Chemical Engineering 412

Introductory Nuclear Engineering

Lecture 26

Commercial Nuclear Accidents

Spiritual Thought

Face the future with optimism. I believe we are standing on the threshold of a new era of growth, prosperity, and abundance. Barring a calamity or unexpected international crisis, I think the next few years will bring a resurgence in the economy as new discoveries are made in communication, ***medicine***, ***energy***, ***transportation***, physics, ***computer technology***, and ***other fields*** of endeavor.

Many of these discoveries, as in the past, will be ***the result of the Spirit whispering insights into and enlightening the minds of truth-seeking individuals***. Many of these discoveries will be made for the purpose of helping to bring to pass the purposes and work of God and the quickening of the building of His kingdom on earth today. With these discoveries and advances will come new employment opportunities and prosperity *for those who work hard and especially to those who strive to keep the commandments of God*. This has been the case in other significant periods of national and international economic growth.

-Elder M. Russell Ballard

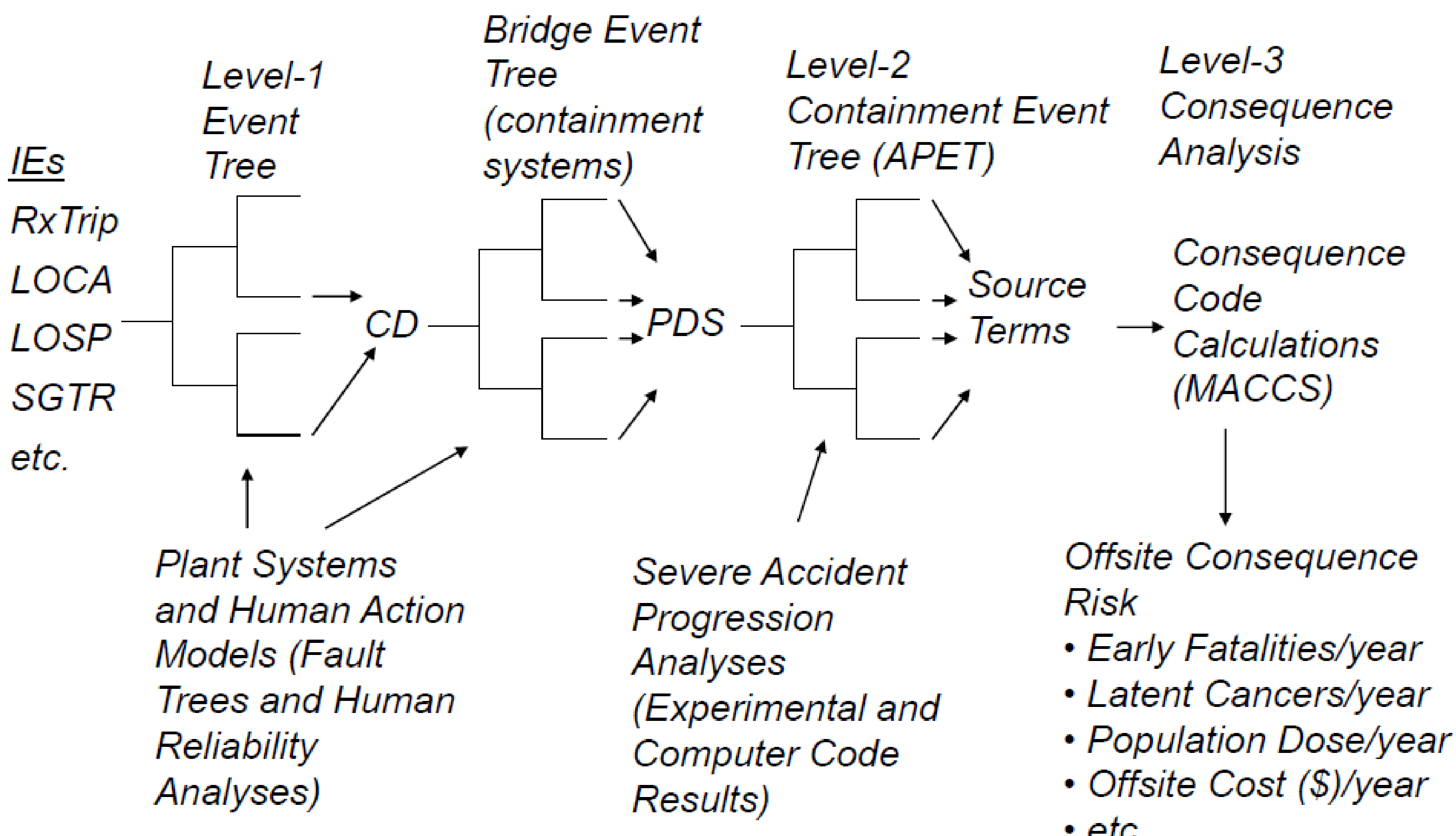
BYU Idaho Commencement Remarks

April 6, 2012

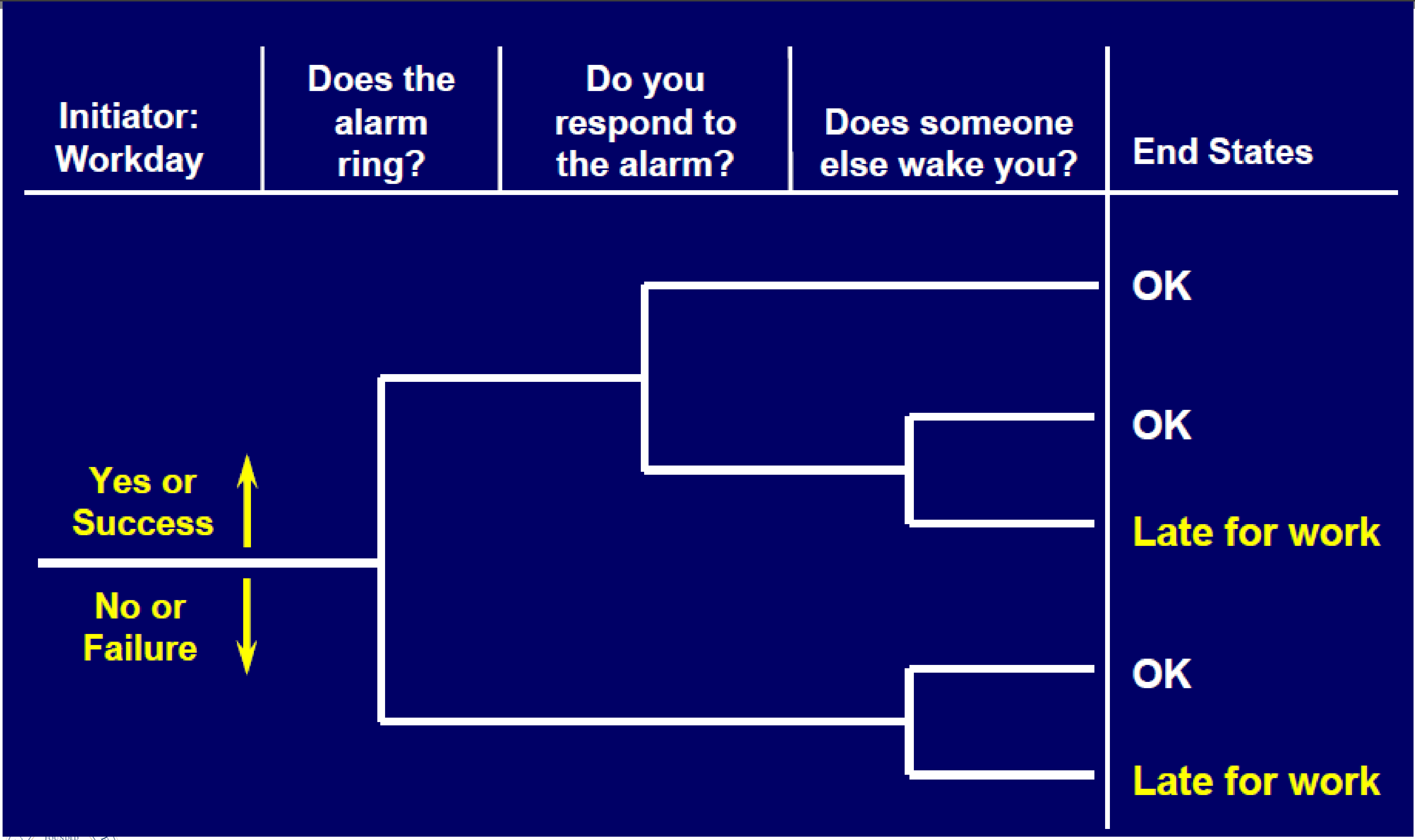
Probability Risk Assessment

$$\text{Risk}\left[\frac{\text{Consequence Magnitude}}{\text{Unit of Time}}\right] =$$

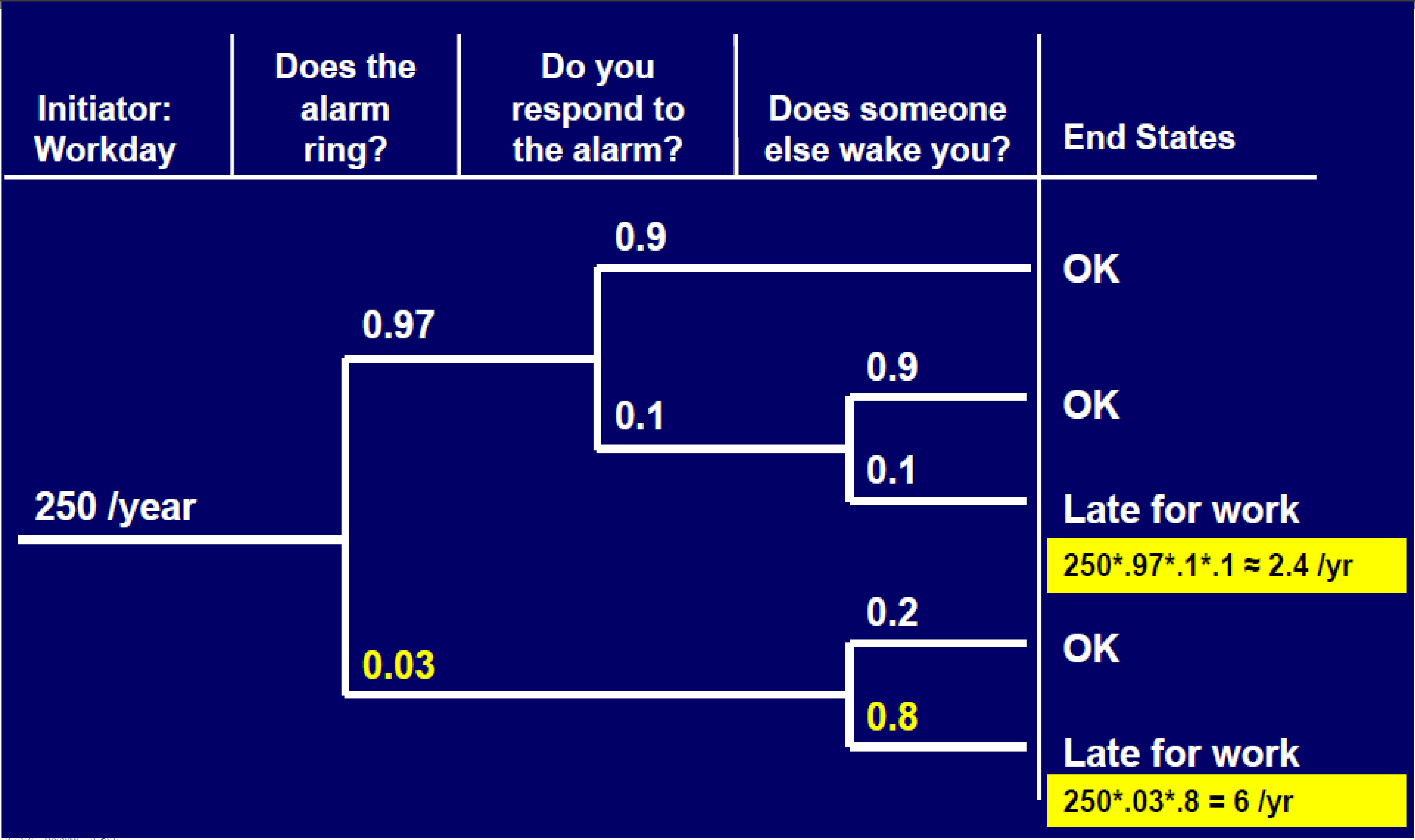
$$\text{Frequency}\left[\frac{\text{Events}}{\text{Unit of Time}}\right] \times \text{Consequences}\left[\frac{\text{Magnitude}}{\text{Event}}\right]$$



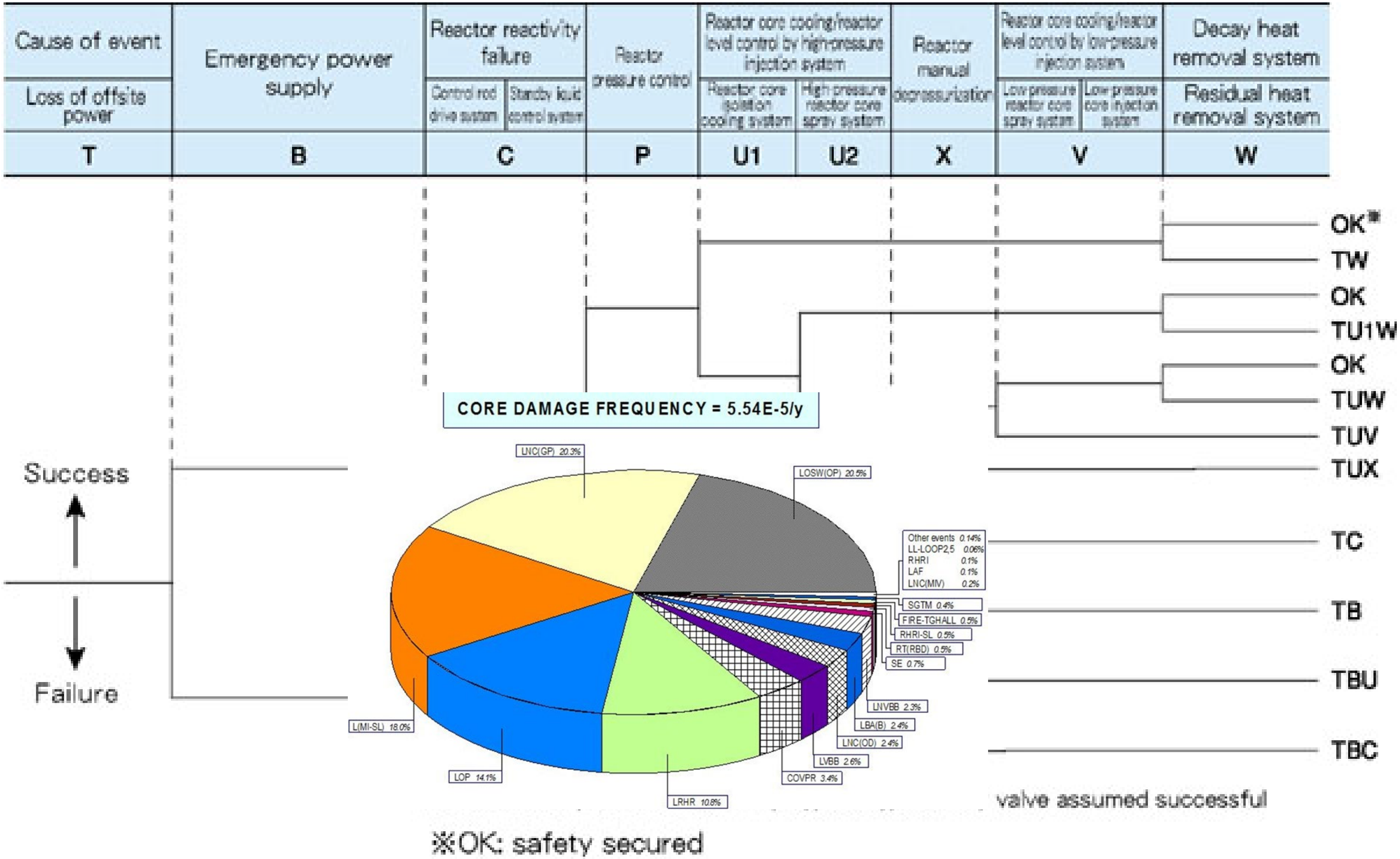
Probabilistic Example



Probabilistic Example



Sample = LOPA

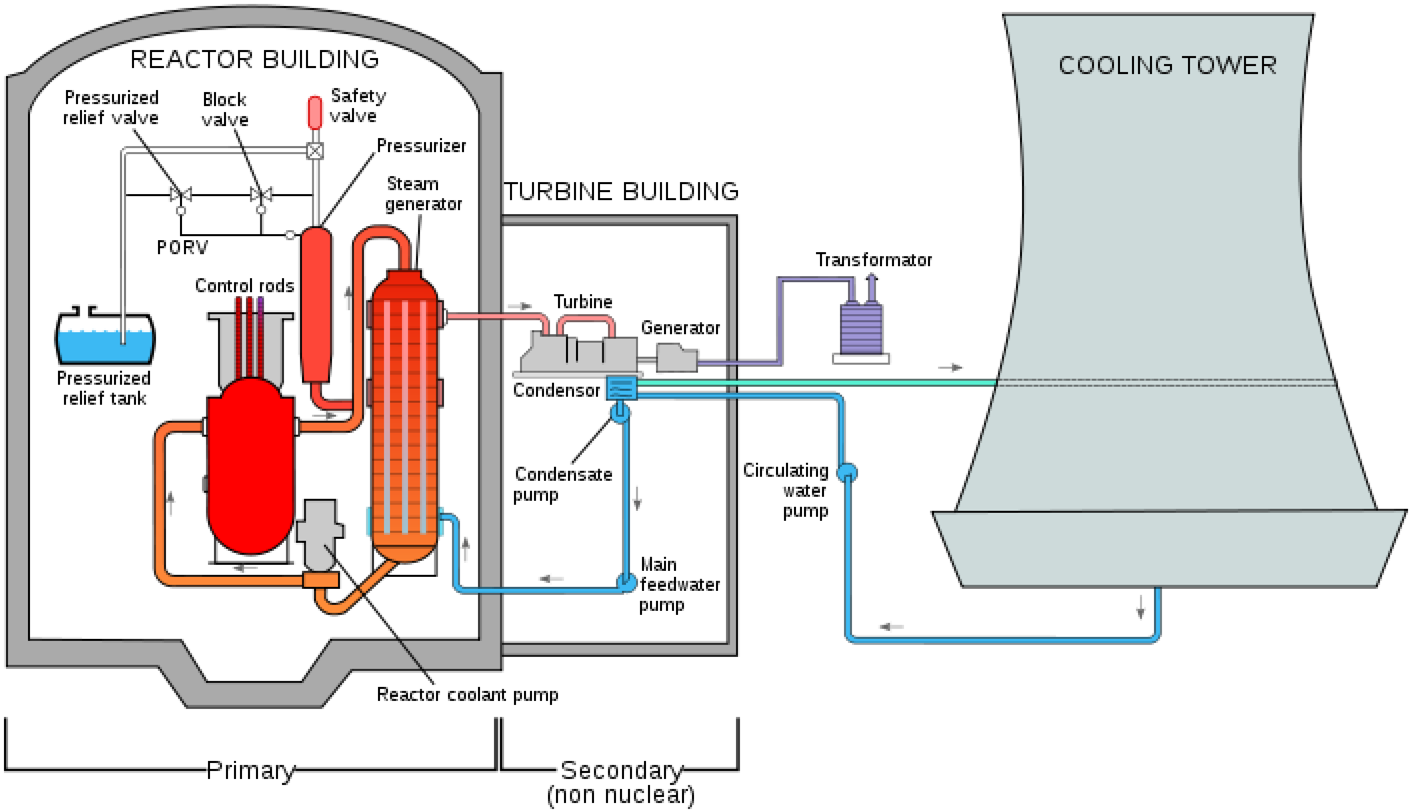


Cause of event
Loss of offsite power
T
Emergency power supply
B
Reactor reactivity failure
Control rod drive system
Standby liquid control system
C
Reactor pressure control
P
Reactor core cooling/reactor level control by high-pressure injection system
Reactor core isolation cooling system
U1
High pressure reactor core spray system
U2
Reactor manual decompressurization
X
Reactor core cooling/reactor level control by low-pressure injection system
Low pressure reactor core spray system
Low pressure core injection system
V
Decay heat removal system
Residual heat removal system
W
OK*
TW
OK
TU1W
OK
TUW
TUV
TUX
TC
TB
TBU
TBC
Success
Failure
CORE DAMAGE FREQUENCY = 5.54E-5/y
LNC(GP) 20.3%
LOSW(OP) 20.5%
Other events 0.14%
LL-LOOP2,5 0.06%
RHRI 0.1%
LAF 0.1%
LNC(MIV) 0.2%
SGTM 0.4%
FIRE-TGHALL 0.5%
RHRI-SL 0.5%
RT(RBD) 0.5%
SE 0.7%
LNVBB 2.3%
LBA(B) 2.4%
LNC(OD) 2.4%
LVBB 2.6%
COVPR 3.4%
LRHR 10.8%
LOP 14.1%
L(MI-SL) 18.0%
valve assumed successful
※OK: safety secured

Three Mile Island

March 28, 1979 - South of Harrisburg – Capital of Pennsylvania

Three Mile Island PWR



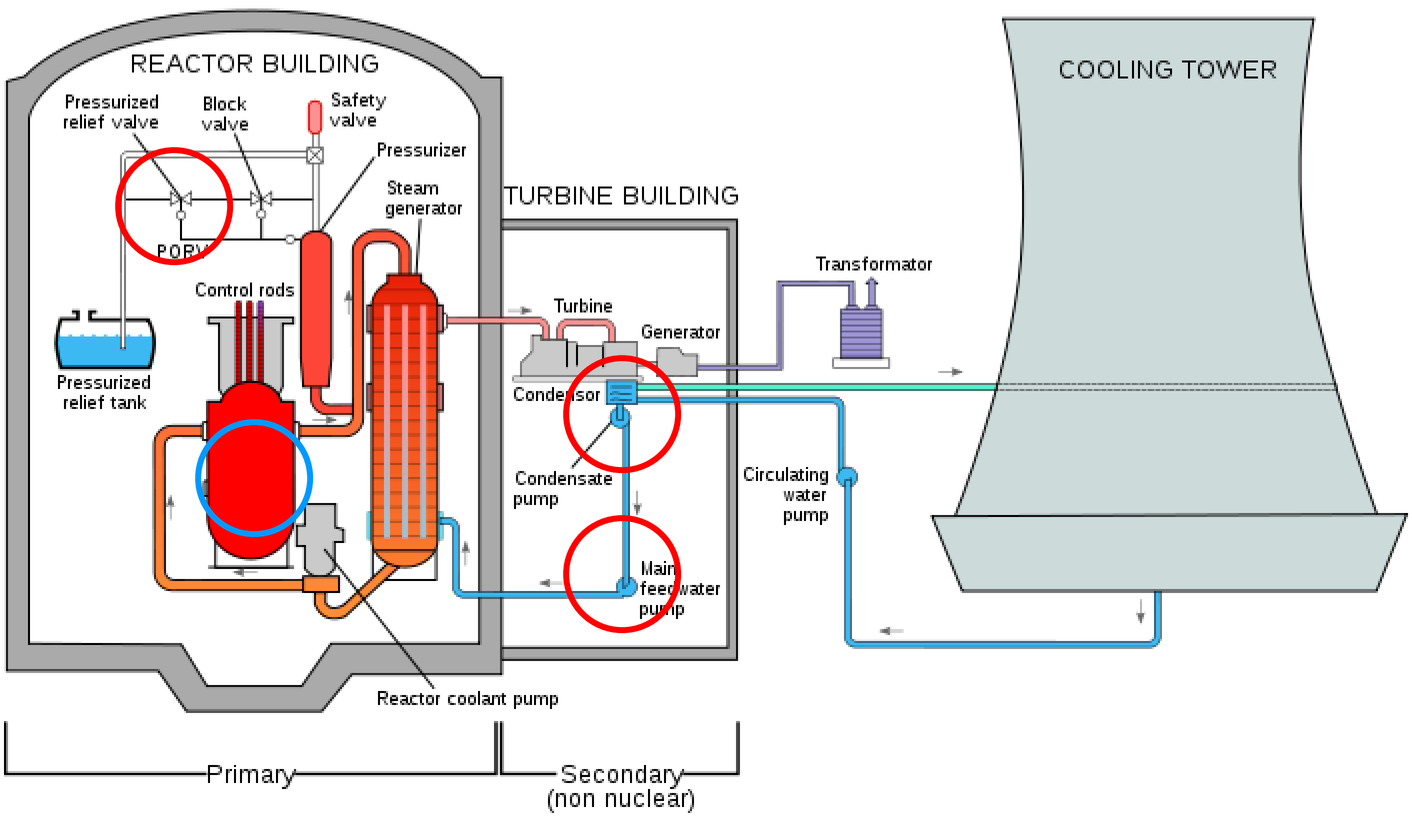
Timeline

- December 31, 1978 – Unit 2 begins commercial operation
- Thursday, March 28, 1979 – Unit 2 experiences equipment and procedure failures resulting in partial core meltdown
- Saturday March 30 – Gas (hydrogen) bubble in reactor leads to evacuation readiness plans, suggested evacuation for pregnant women and children within 5 miles, and 140,000 person voluntary evacuation
- April 6 – Evacuation order lifted

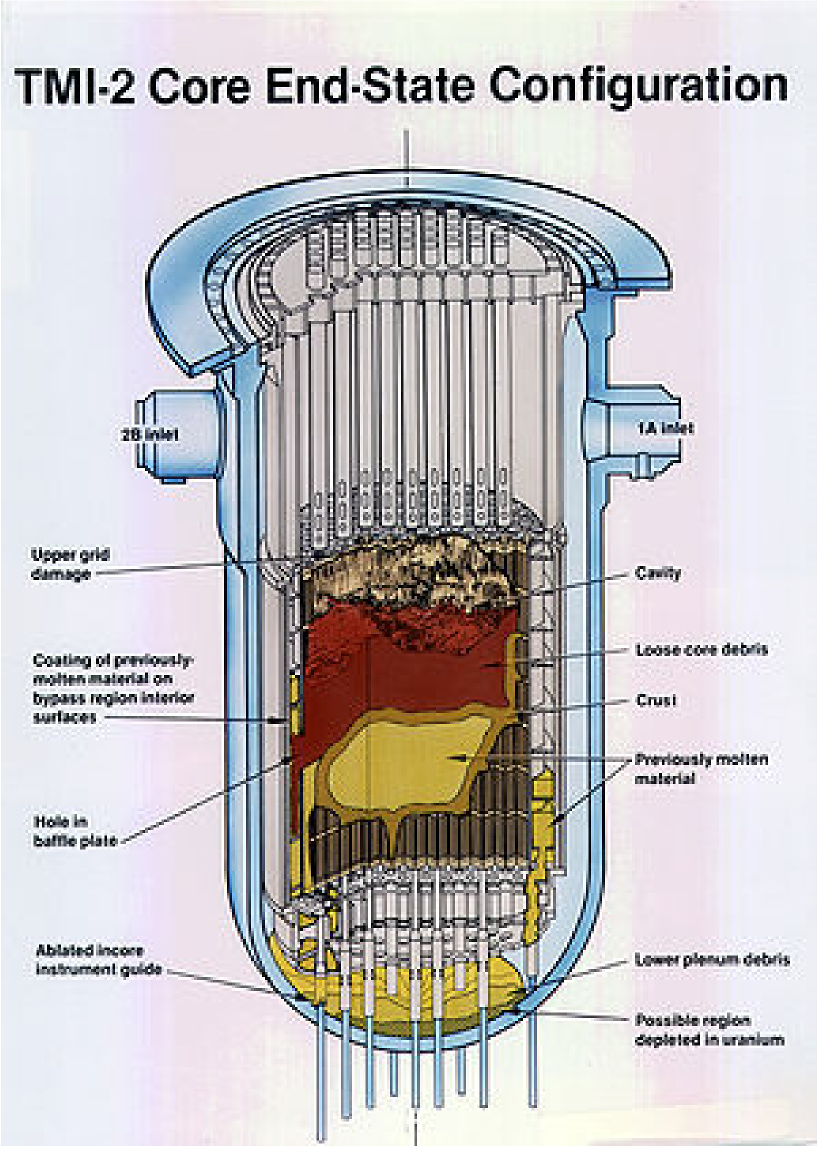
Accident History

- Running at 97% full load when TMI-1 is shut down for refueling
- Pumps in condensate polishing system failed (either mechanically or electrically – still not known) followed immediately by main feed water pump failure.
- Automatic SCRAM trigger and turbine shutdown.
- All control rods fully inserted
- Pilot-operated relief valve (PORV) in the primary system stuck open, allowing reactor coolant to escape
- Operators did not recognize Loss of Coolant condition, overrode an automatic emergency coolant response because of mistaken belief that the reactor had too much coolant
- Reactor continues generating decay heat – but no heat removal since turbines tripped.
- Three auxiliary feedwater pumps activated, but valves had been closed for maintenance, so no water flowed (closing valves while reactor is operational is a severe rule violation).

Three Mile Island PWR



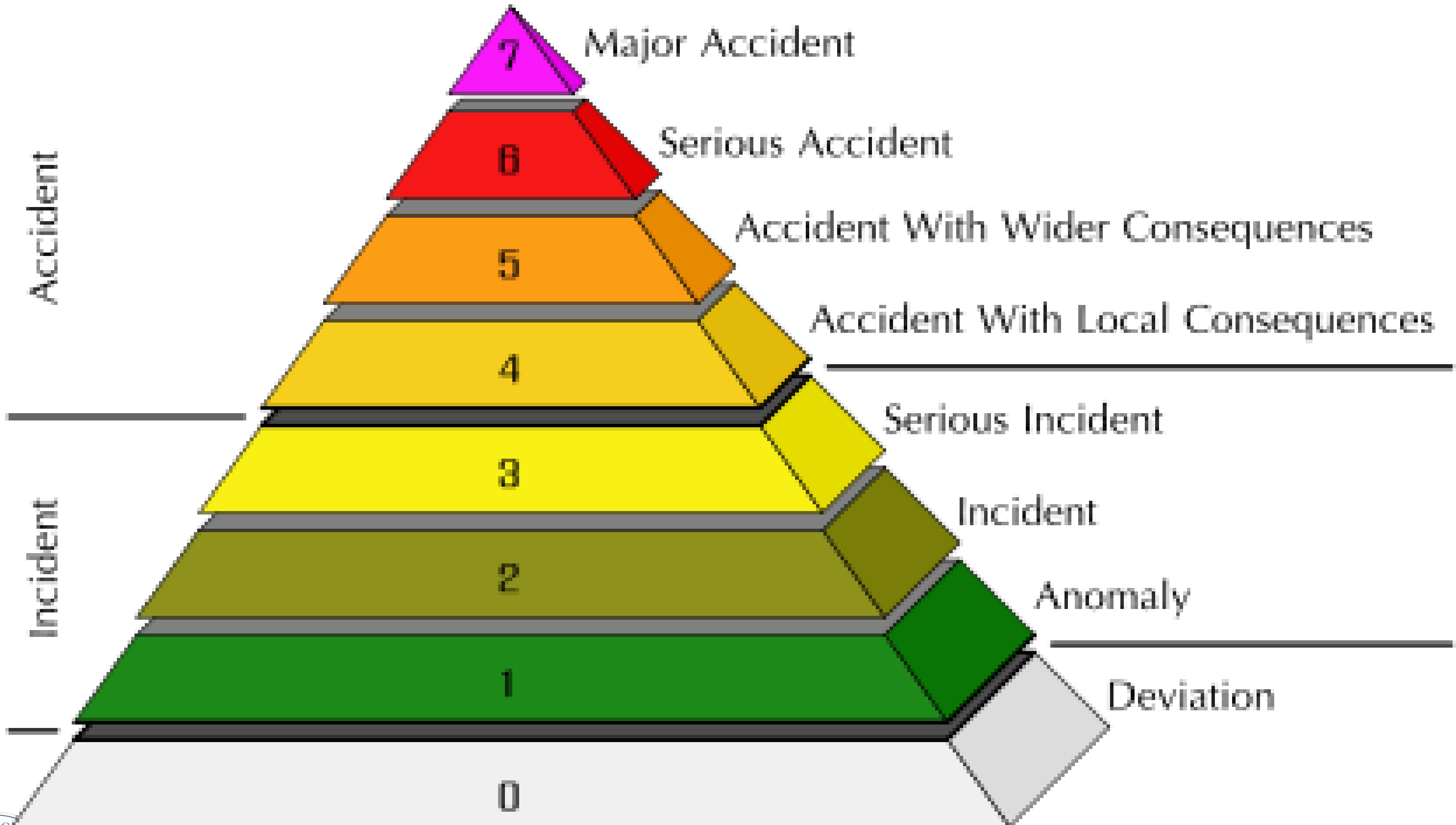
Three Mile Island



Consequences

- approximately 2.5 million curies of radioactive noble gases (mainly Xe and Kr) and 15 curies of radioiodines were released to the environment, primarily through the PORV
- 140,000 pregnant women and pre-school-age children evacuated
- 1.4 mrem dose to 2 million people near plant
  - 3.2 mrem dose comes from a chest x-ray
  - 80 mrem dose comes from living in Denver instead of Harrisburg
- no perceptible effect on cancer or other health issue incidence in residents near the plant – consensus opinion (one report dissents)
- significant impact on industry, regulation, and safety

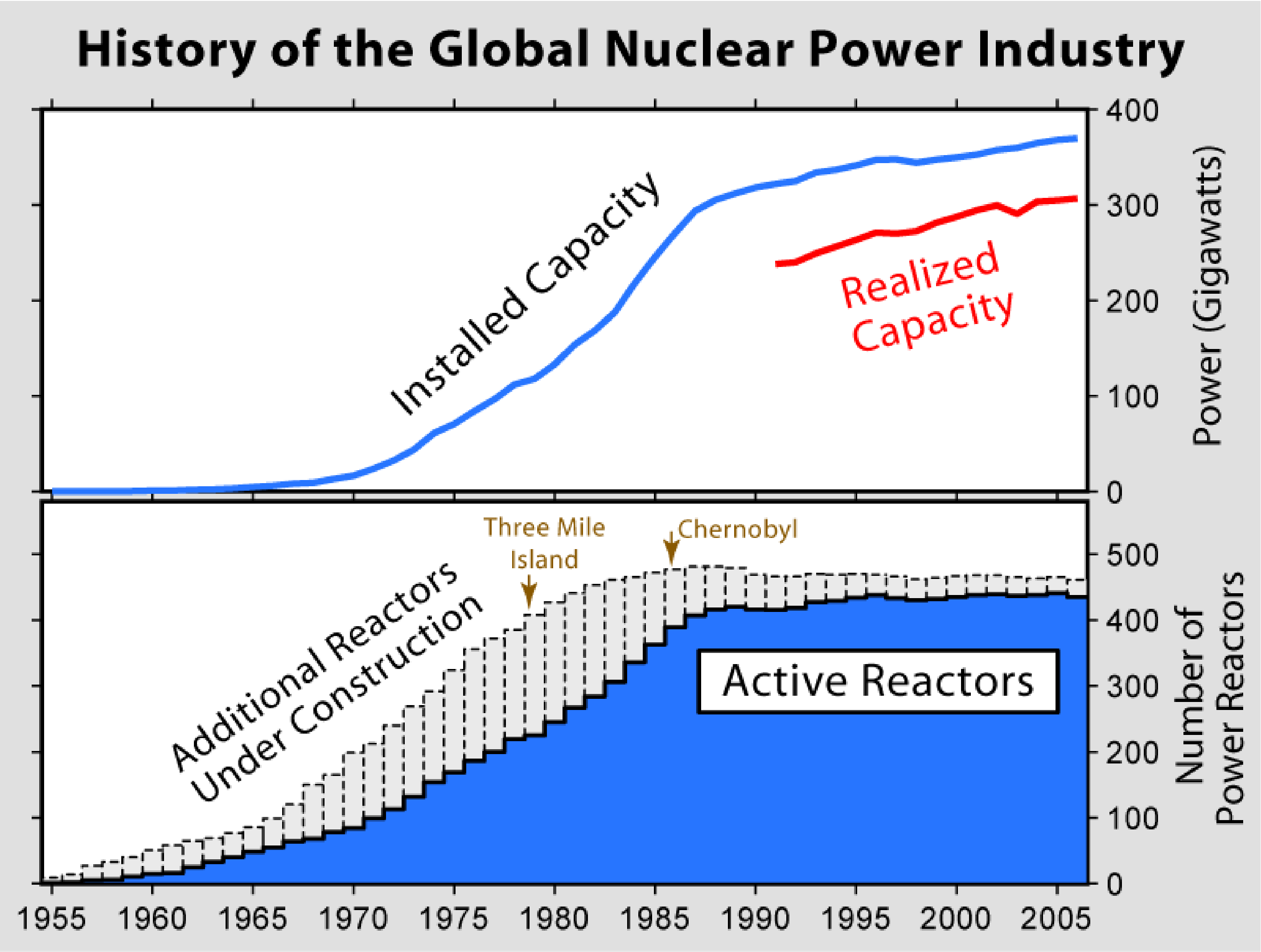
International Nuclear Event Scale



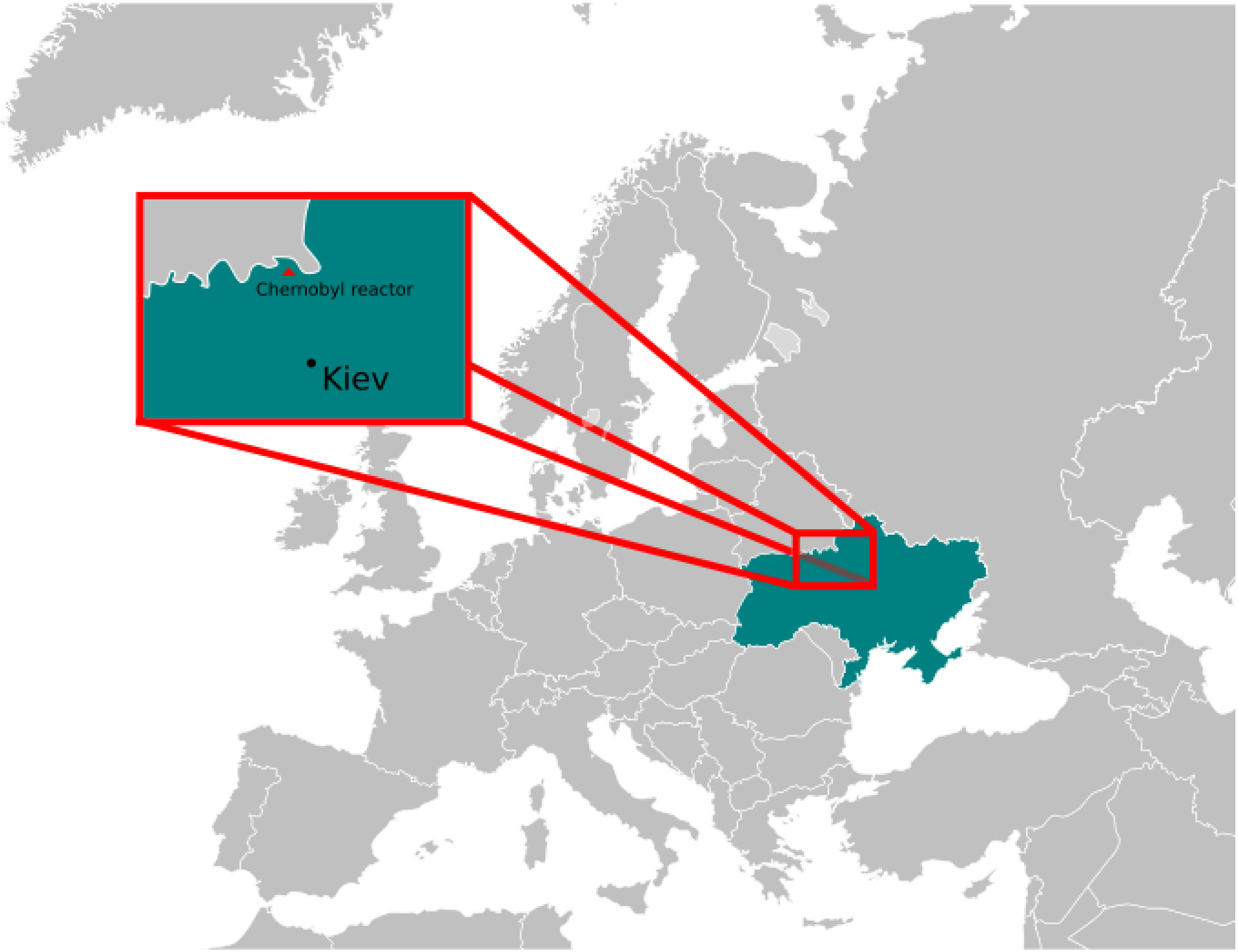
Examples of Level 5 Accidents

- Windscale fire (United Kingdom), 10 October 1957.[7] Annealing of graphite moderator at a military air-cooled reactor caused the graphite and the metallic uranium fuel to catch fire, releasing radioactive pile material as dust into the environment.
- Three Mile Island accident near Harrisburg, Pennsylvania (United States), 28 March 1979.[8] A combination of design and operator errors caused a gradual loss of coolant, leading to a partial meltdown. Radioactive gases were released into the atmosphere, no deaths have been attributed to this accident.
- First Chalk River accident,[9][10] Chalk River, Ontario (Canada), 12 December 1952. Reactor core damaged.
- Lucens partial core meltdown (Switzerland), 21 January 1969. A test reactor built in an underground cavern suffered a loss-of-coolant accident during a startup, leading to a partial core meltdown and massive radioactive contamination of the cavern, which was then sealed.[citation needed]
- Goiânia accident (Brazil), 13 September 1987. An unsecured caesium chloride radiation source left in an abandoned hospital was recovered by scavenger thieves unaware of its nature and sold at a scrapyard. 249 people were contaminated and 4 died.

Effect on Global Nuclear Industry

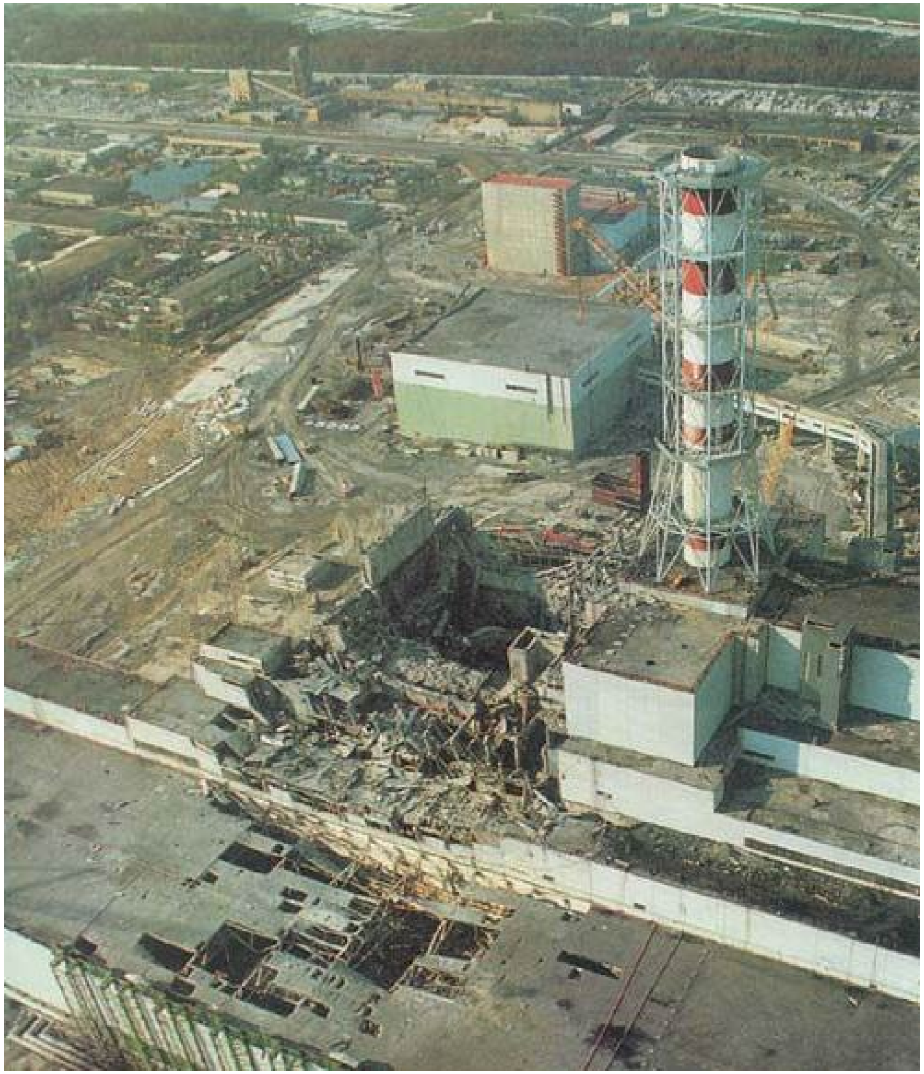


Chernobyl Location

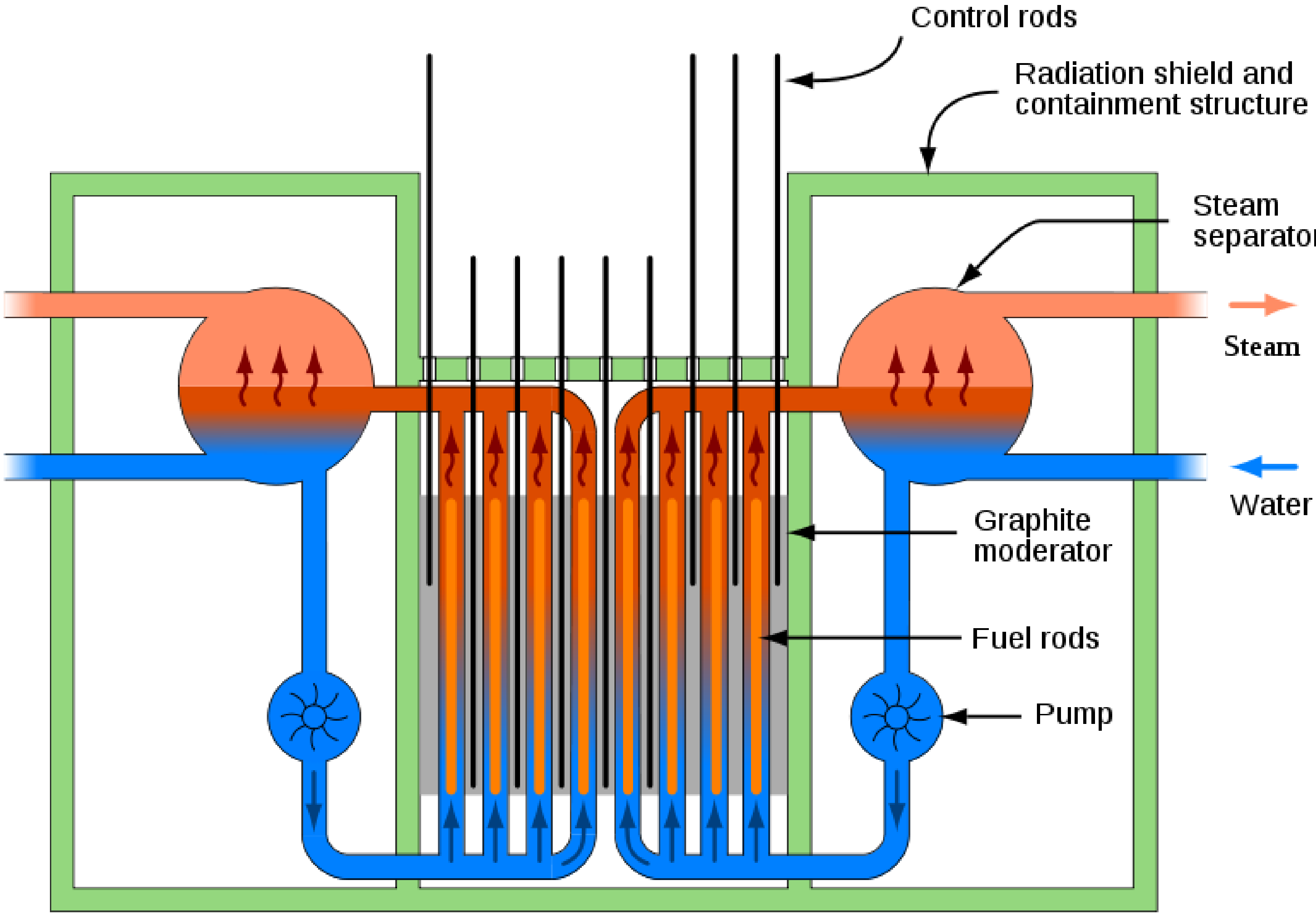


Chernobyl Contamination Map

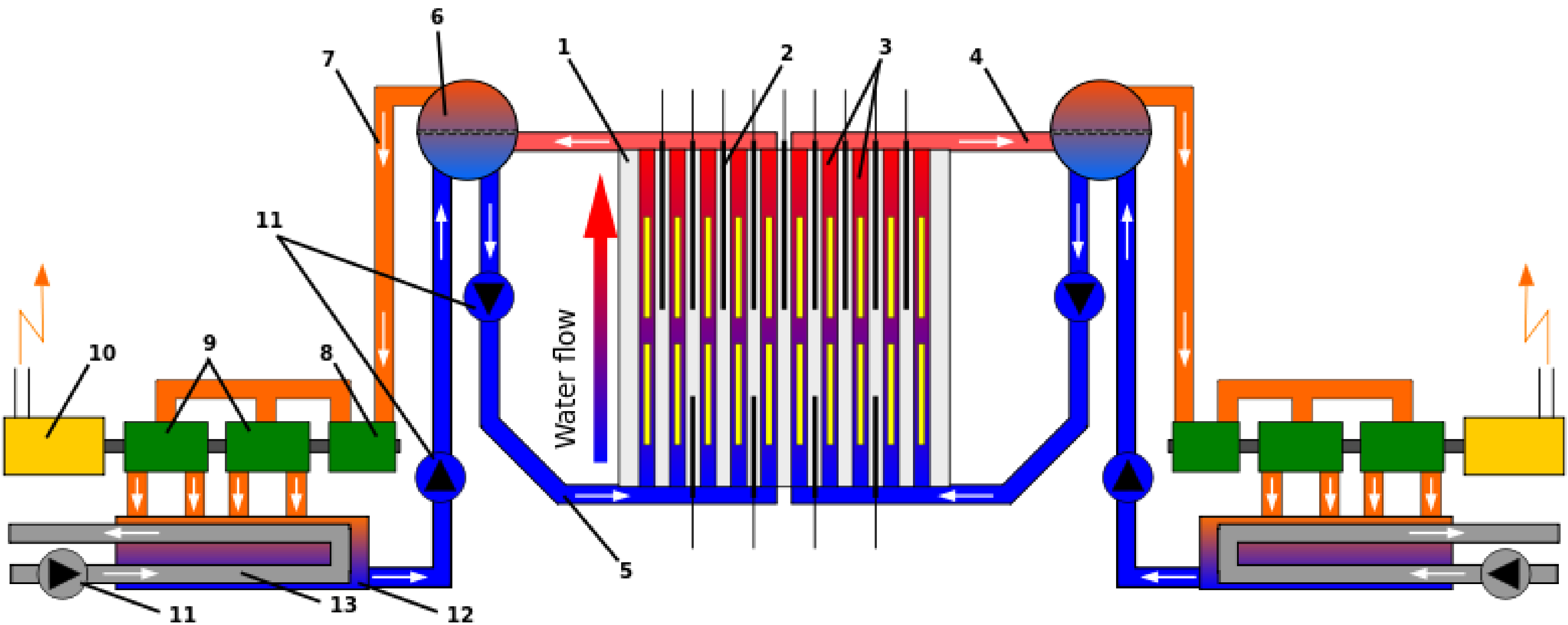
Chernobyl Reactor #4



RBMK Reactor Design



Ancillary Systems



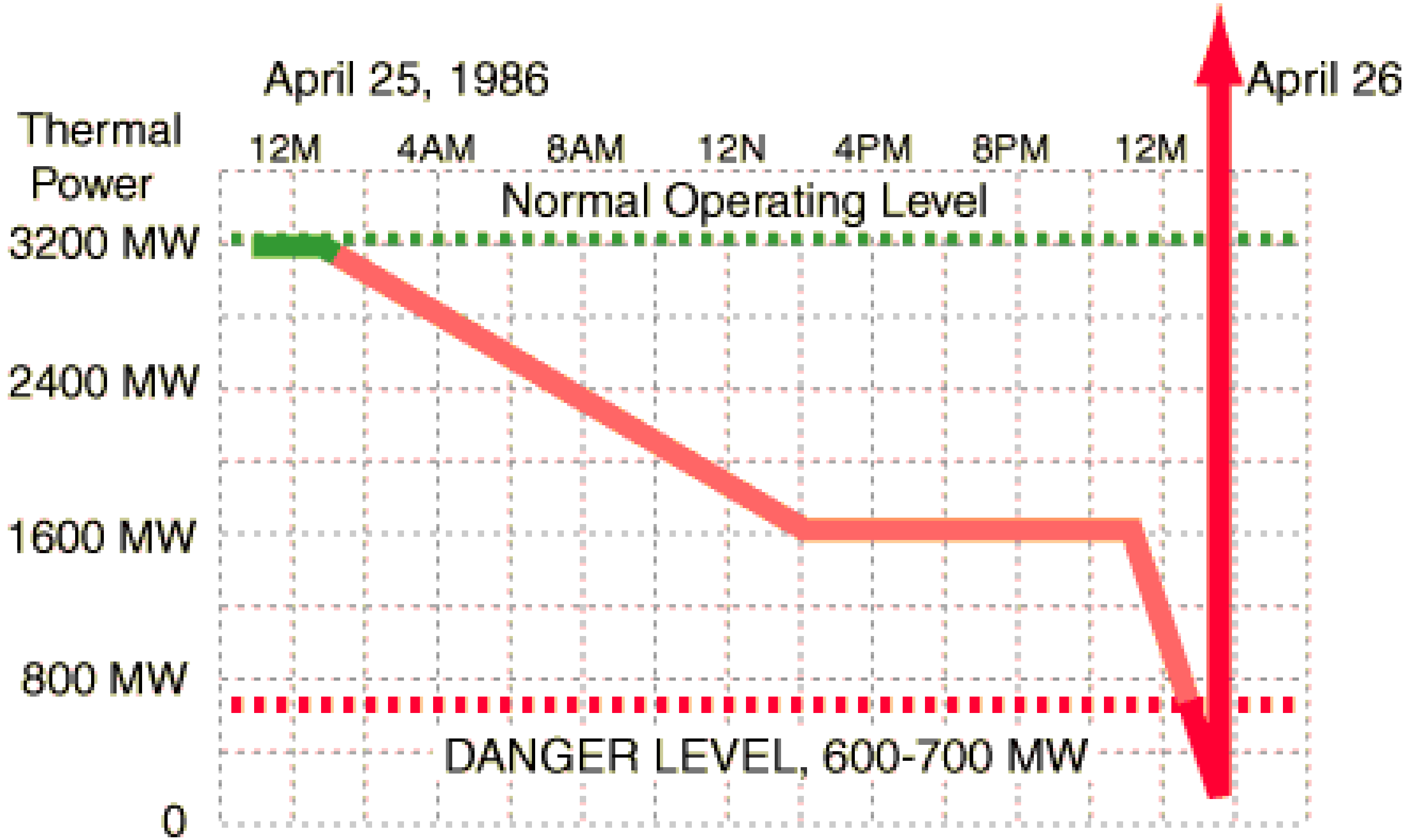
Legend :

1. Graphite moderated reactor core
2. Control rods
3. Pressure channels with fuel rods
4. Water/steam mixture
5. Water
6. Water/steam separator
7. Steam inlet
8. High-pressure steam turbine
9. Low-pressure steam turbine
10. Generator
11. Pump
12. Steam condenser
13. Cooling water (from river, sea, etc.)

Timeline – April 25, 1986

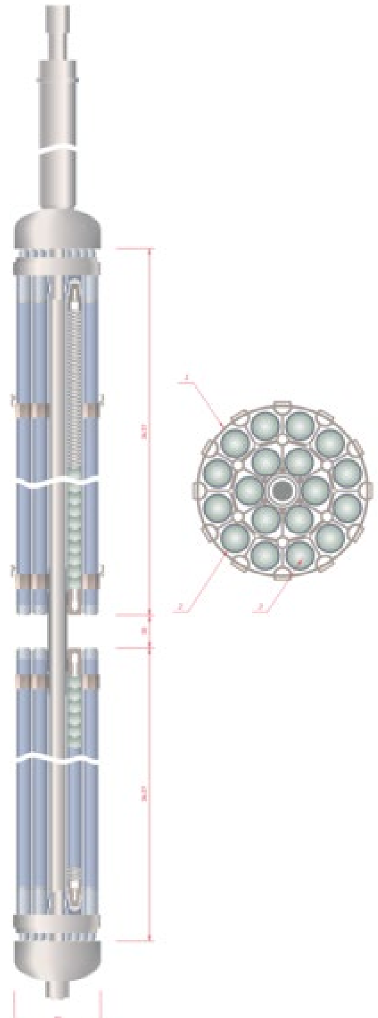
1:00 am	The reactor was running at full power with normal operation. Steam power was directed to both turbines of the power generators. Slowly the operators began to reduce power for the test. The purpose of the test was to observe the dynamics of the RMBK reactor with limited power flow.
1:05 pm	Twelve hours after power reduction was initiated the reactor reached 50% power. Now only one turbine was needed to take in the decreased amount of steam caused by the power decrease and turbine #2 was switched off.
2:00 pm	Under the normal procedures of the test the reactor would have been reduced to 30% power, but the Soviet electricity authorities refused to allow this because of an apparent need for electricity elsewhere, so the reactor remained at 50% power for another 9 hours.
April 26 Day 2	
12:28 am	The Chernobyl staff received permission to resume the reactor power reduction. One of the operators made a mistake. Instead of keeping power at 30%, he forgot to reset a controller which caused the power to plummet to 1% because of water which was now filling the core, and xenon (a neutron absorber) which was building up in the reactor. This amount of power was too low for the test. The water added to the reactor is heated by the nuclear reaction and turned into steam to turn the turbines of the generator.
1:00-1:20 am	The operator forced the reactor up to 7% power by removing all but 6 of the control rods. This was a violation of procedure and the reactor was never built to operate at such low power. The RBMK reactor is unstable when its core is filled with water. The operator tried to take over the flow of the water which was returning from the turbine manually which is very difficult because small temperature changes can cause large power fluctuations. The operator was not succesful in getting the flow of water corrected and the reactor was getting increasingly unstable. The operator disabled emergency shutdown procedures because a shutdown would abort the test.
1:22 am	By 01:22, when the operators thought they had the most stable conditions, they decided to start the test. The operator blocked automatic shutdown on low water level and the loss of both turbines because of a fear that a shutdown would abort the test and they would have to repeat tests.
1:23 am (The test begins)	The remaining turbine was shut down
1:23:40 am	Power in the reactor began to gradually rise because of the reduction in water flow caused by the turbine shutdown which lead to an increase in boiling. The operator initiated manual shut down which lead to a quick power increase due to the control rod design.
1:23:44 am	Disaster Point- The reactor reached 120 times its full power. All the radioactive fuel disintegrated, and pressure from all of the excess steam which was supposed to go to the turbines broke every one of the pressure tubes and blew off the entire top shield of the reactor.

Reactor Power Levels

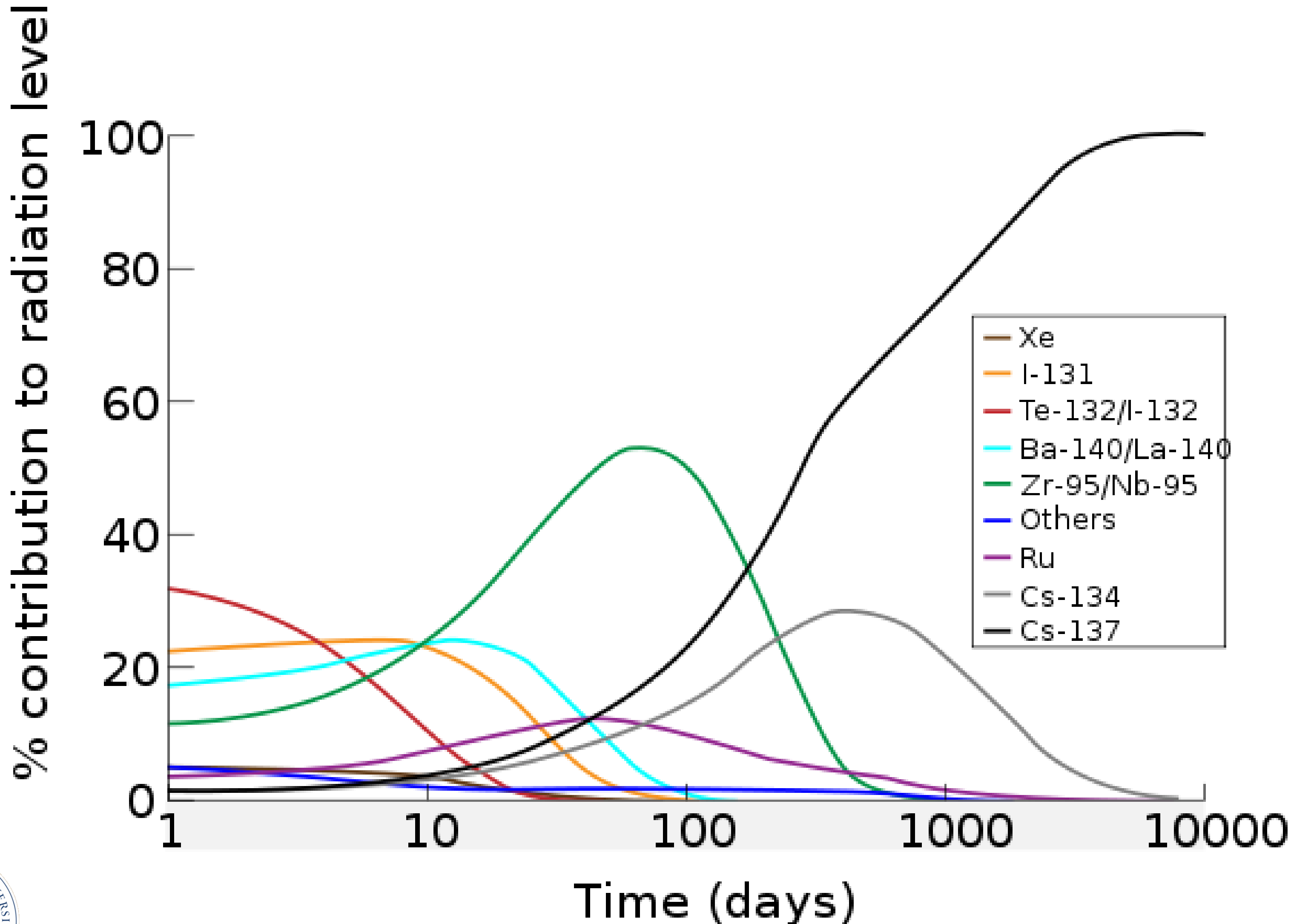


A Chronology of Disaster, Chernobyl

RBMK Fuel Rod Assembly



Radiation Sources



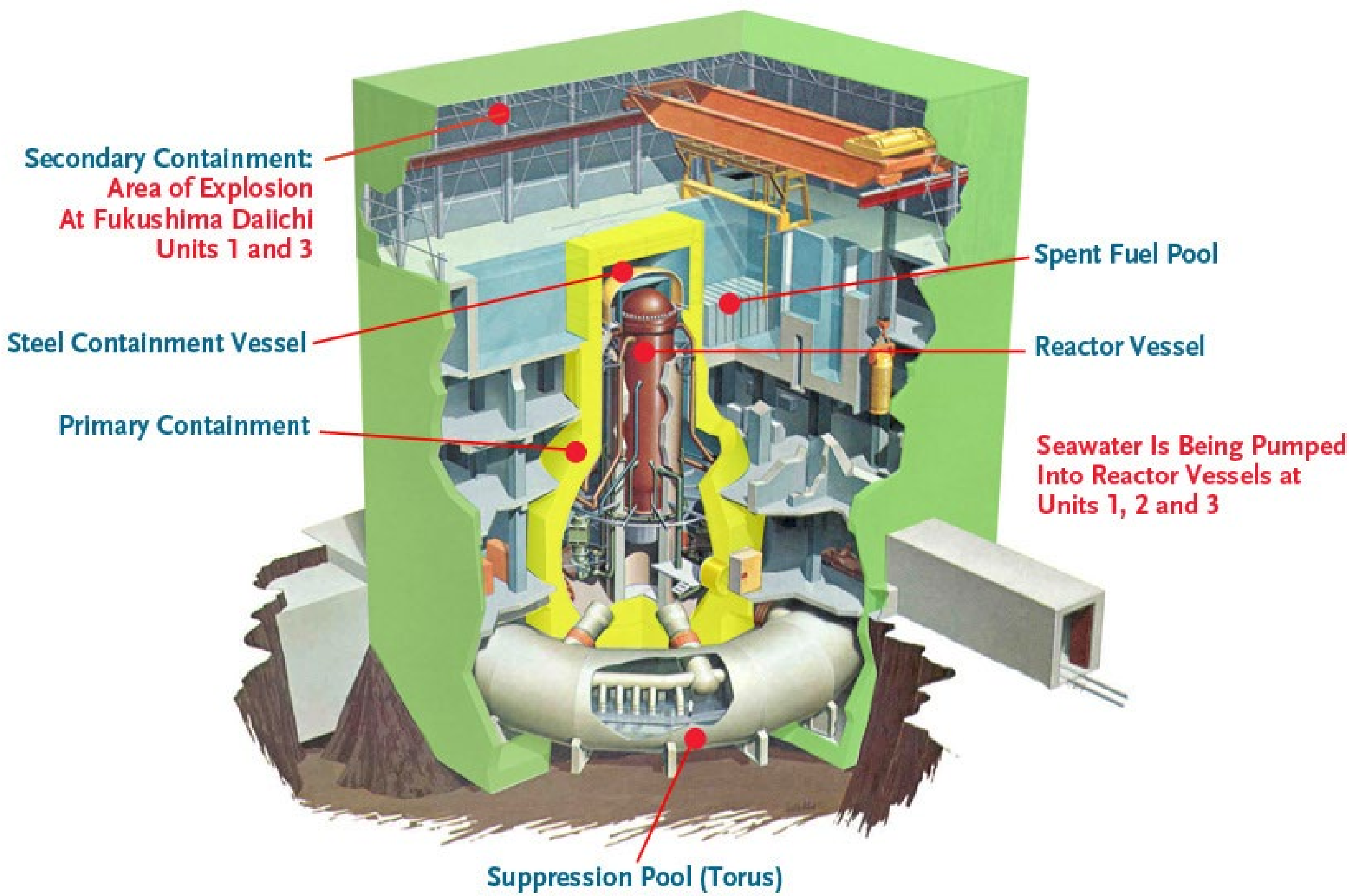
Fukushima Observations

- **Not a Public Heath Catastrophe**
  - Inconsequential to Earth/Tsunami Impacts
  - The Fukushima event rating was provisionally increased from level 5 to level 7 by Japanese officials on April 12, due to computer analyses indicating total discharged iodine-131 and caesium-137 in the early days of the event were sufficient to warrant an increased rating level. This rating increase did not reflect any new event. The radioactive release from Fukushima is very roughly estimated by Japanese officials to be about 10 percent of that released from the Chernobyl accident – with very important differences.

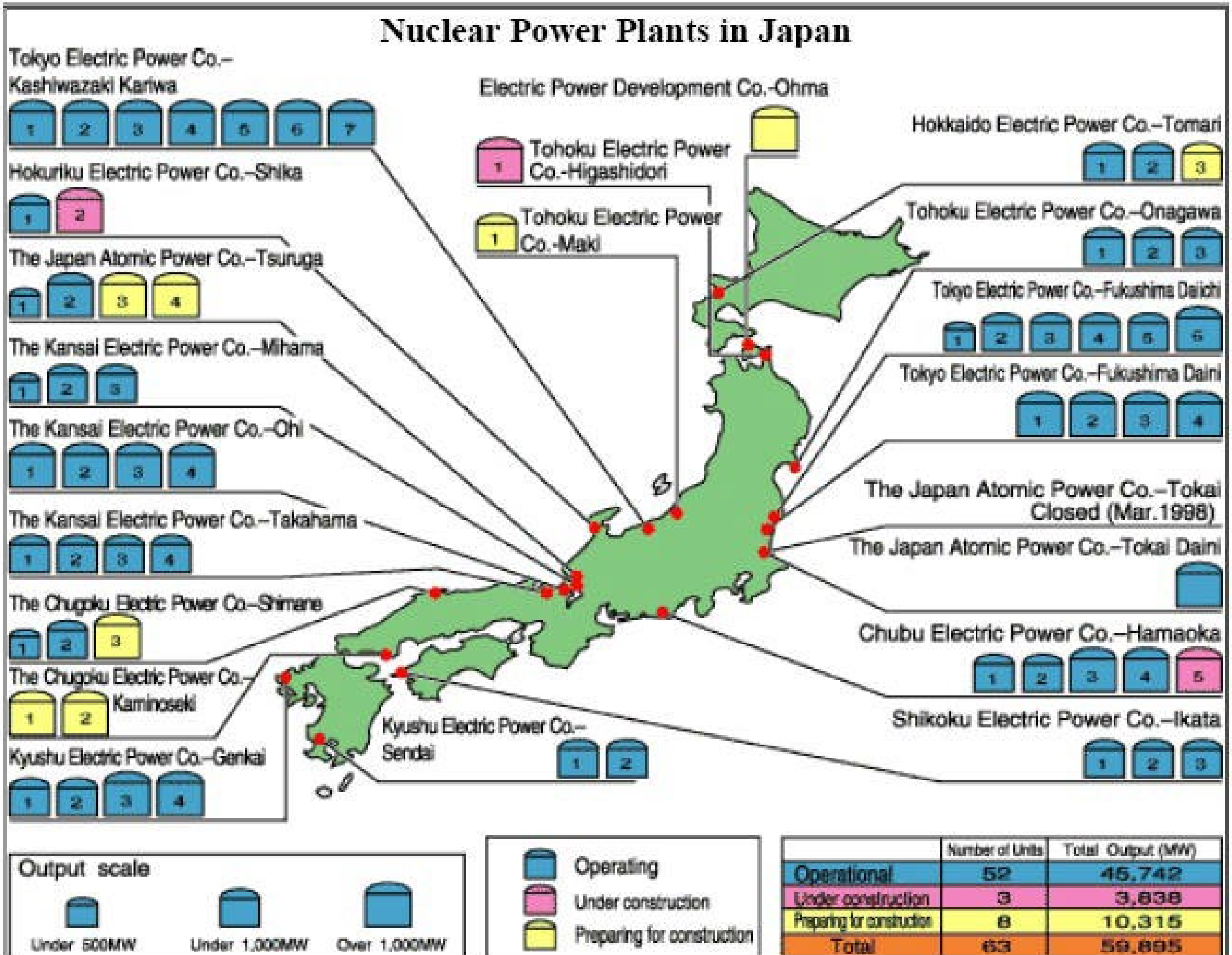
Fukushima Observations

- **Not a Public Heath Catastrophe**
  - The most important difference between Chernobyl and Fukushima is no deaths or illness among the public are expected from the Fukushima incident. The Chernobyl accident emitted radioactive particles high into the atmosphere, which spread downwind across Europe, and a reactor fire continued this process for at least 10 days. Radiation from the Fukushima incident is mostly in the form of liquid runoff into the ocean and low-altitude particles that have frequently blown out into the ocean. At Fukushima, the reactor fuel remains inside the primary containment structures, whereas the Soviet Chernobyl design did not have a containment structure.

Boiling Water Reactor Design At Fukushima Daiichi

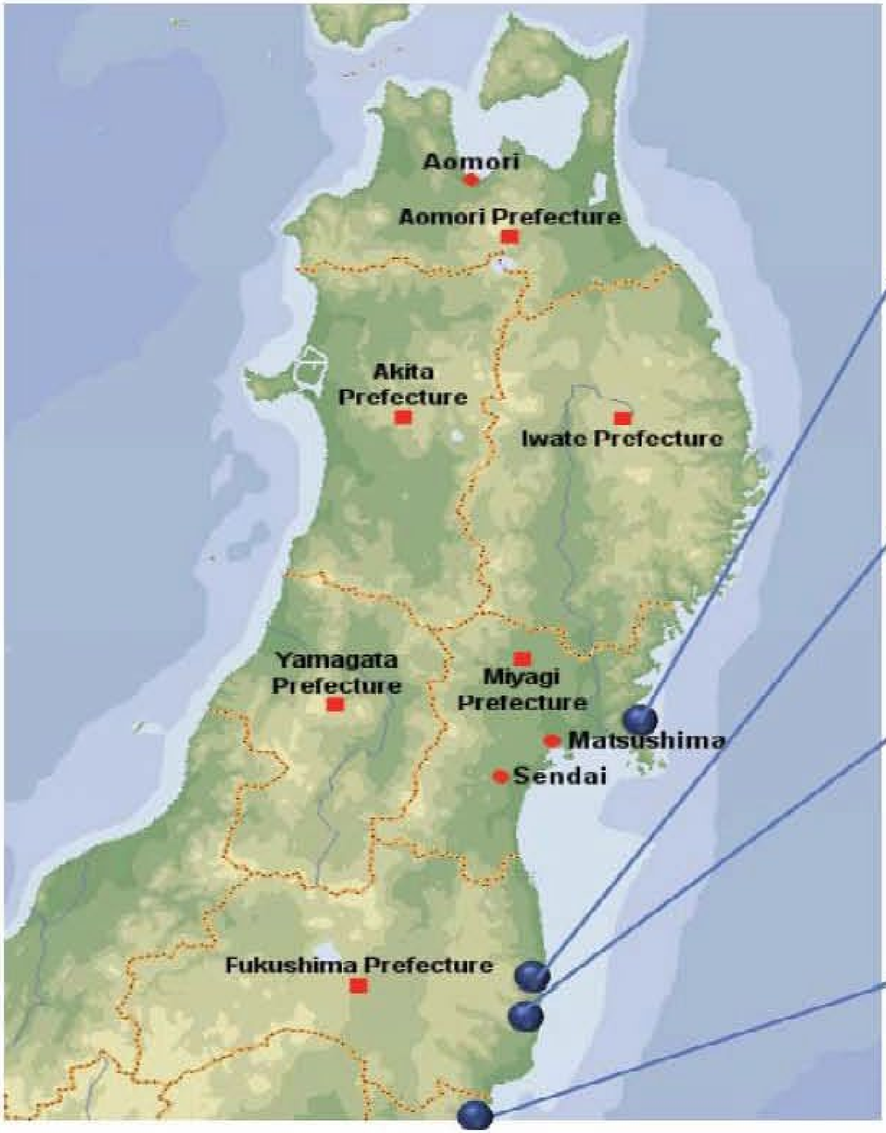


Updated 3/17/11



	Number of Units	Total Output (MW)
Operational	52	45,742
Under construction	3	3,838
Preparing for construction	8	10,315
Total	63	59,895

Location of the Nuclear Installations



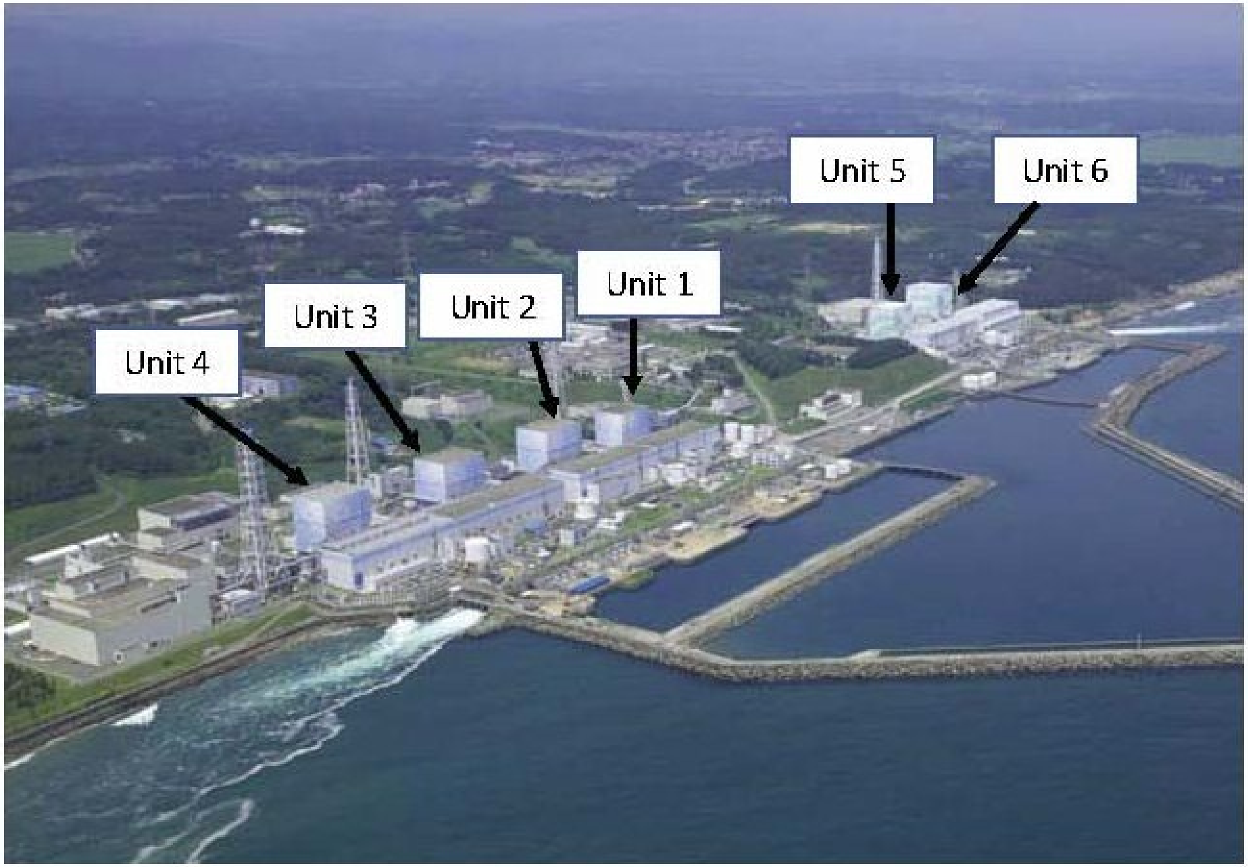
Onagawa
- Unit1: 524 MW, 1984-
- Unit2: 825 MW, 1995-
- Unit3: 825 MW, 2002-

Fukushima I
- Unit1: 460 MW, 1971-
- Unit2: 784 MW, 1974-
- Unit3: 784 MW, 1976-
- Unit4: 784 MW, 1978-
- Unit5: 784 MW, 1978-
- Unit6: 1,100 MW, 1979-

Fukushima II
- Unit1: 1,100 MW, 1982-
- Unit2: 1,100 MW, 1984-
- Unit3: 1,100 MW, 1985-
- Unit4: 1,100 MW, 1987-

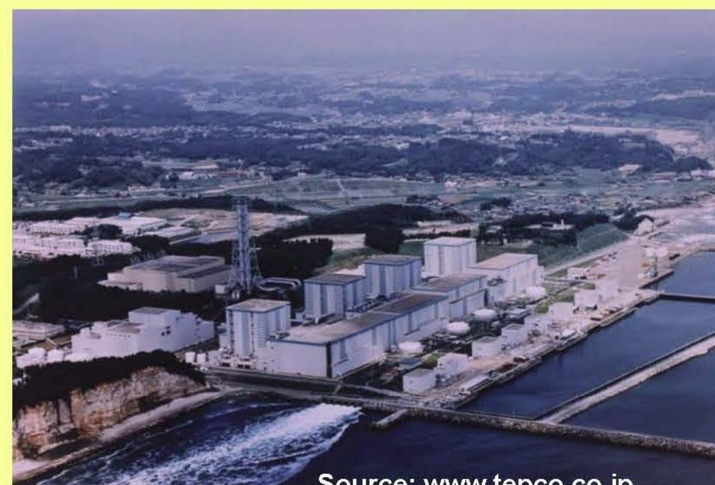
Tokai II (1,100 MW, 1978-)

Outline of Fukushima Dai-ichi NPS



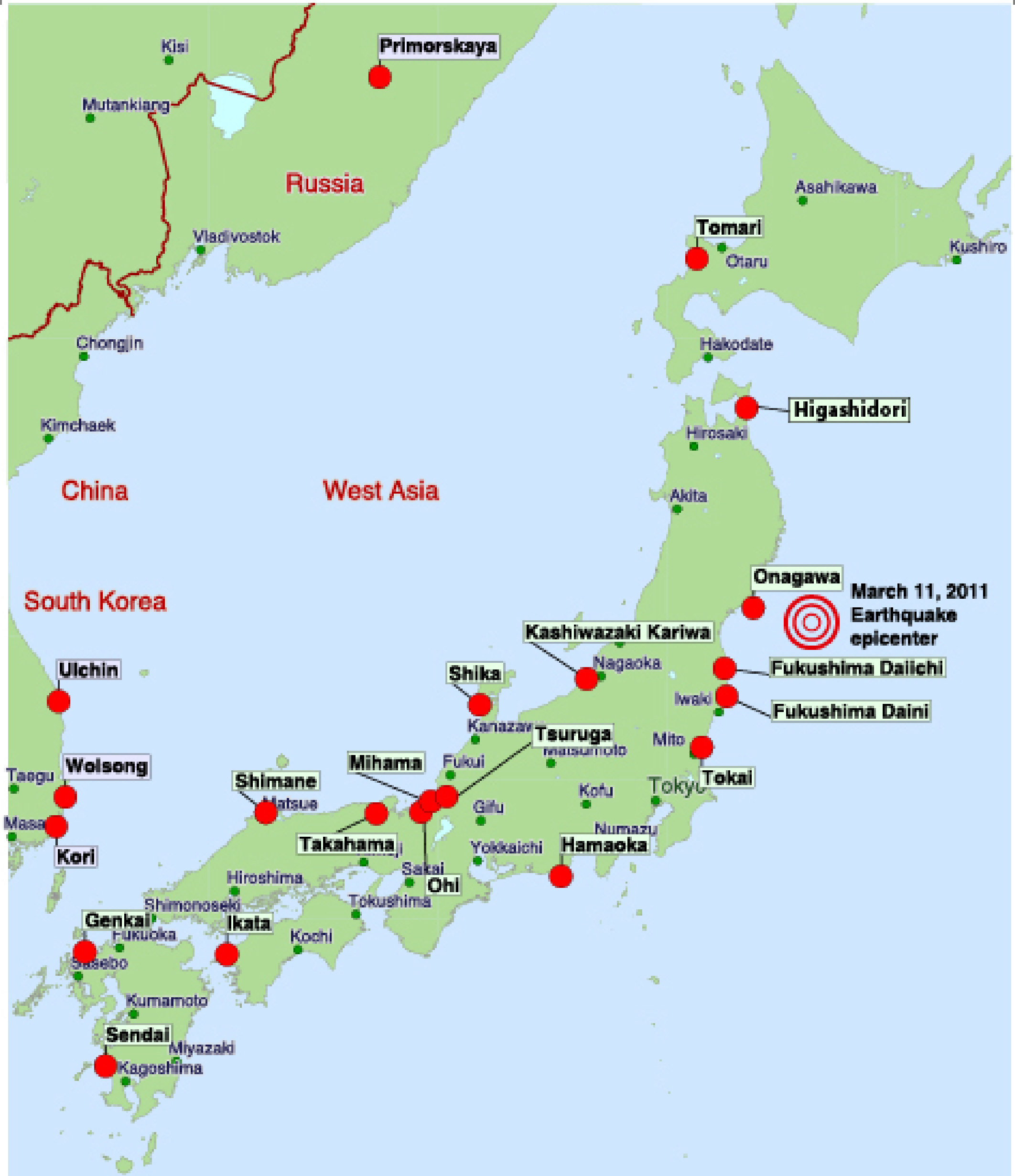
Fukushima Dai-ichi NPP

Fukushima Dai-ni NPP



- **Occurred 14:46 March 11, 2011**
- **Magnitude:9.0 Mw**
- **Epicenter location: 38° 6"N and 142° 51"E, and 24km in depth**
- **It is said that the height of tsunami attacked Fukushima NPP was more than 14m**

Japan's Nuclear Energy Plants

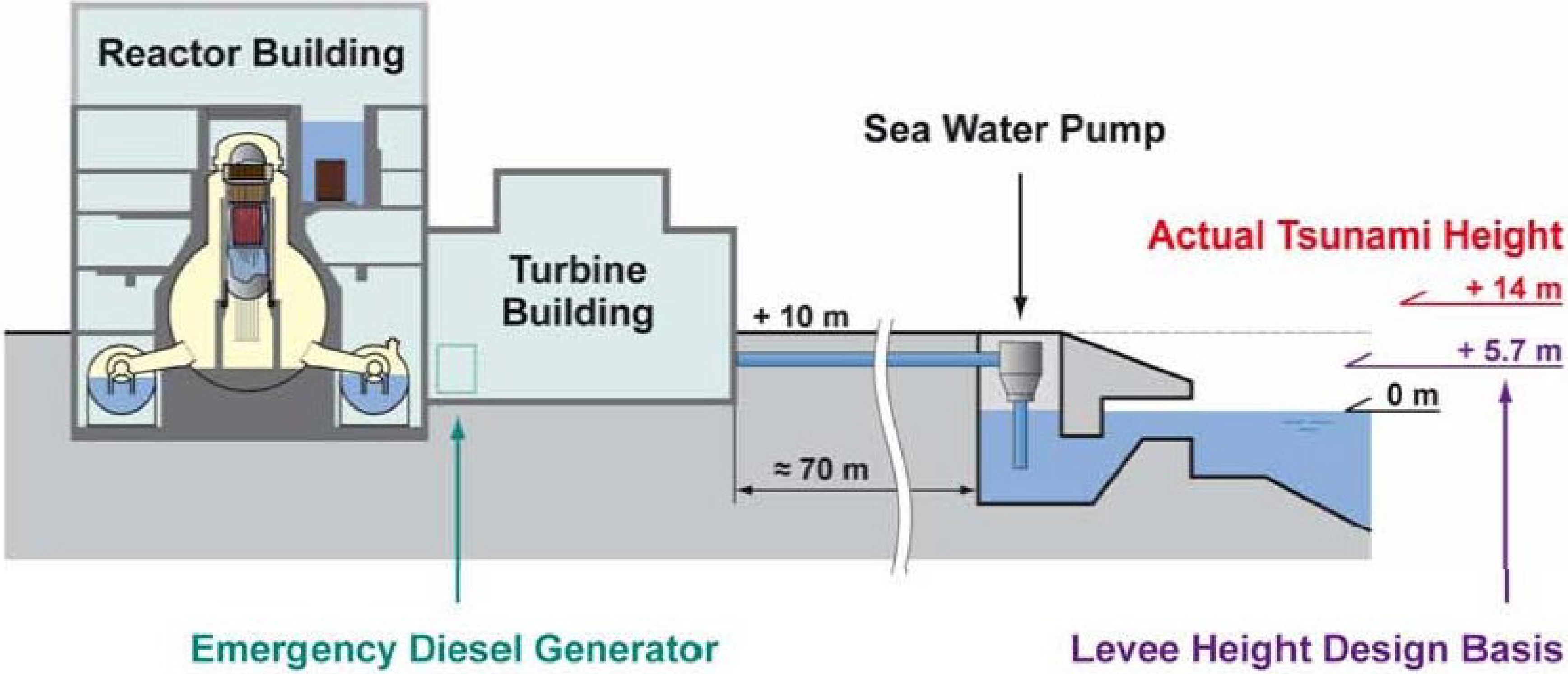


The Real Catastrophe was the Tsunami

- 26,000 (dead &missing) & 130,000 homeless (April 28, 2011)
- Lead four plants at Fukushima I to fuel damage and large releases of radiation

https://www.youtube.com/watch?v=gmlixFM-Bn4&list=PLNspHwmzscYE2-cUkOfHo92ATHZUqqsPH&index=1&feature=iv&src_vid=j0YOXVlPUu4&annotation_id=annotation_1885845763

Some Perspective…

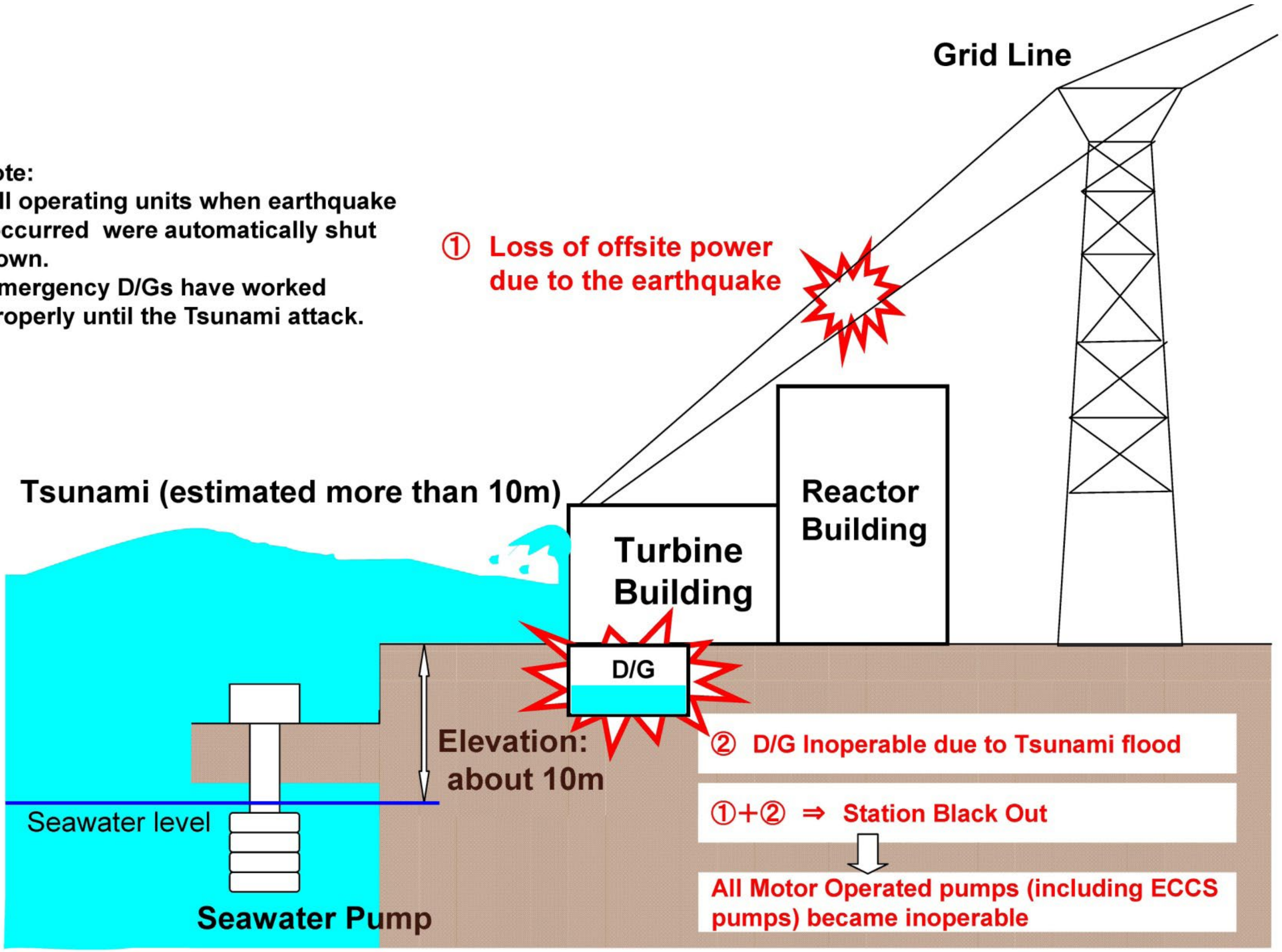


- At Fukushima Daiichi, countermeasures for tsunamis had been established with a design basis height of **5.7 m** above the lowest Osaka Bay water level.
- As additional safety margin, the ground level had been set to as + 10 m.

Source: Janti, 2011 All levels are related to the base level of Onahama Bay

Tsunami Size Was Accident Cause 3/11

Note:
-All operating units when earthquake occurred were automatically shut down.
-Emergency D/Gs have worked properly until the Tsunami attack.



Approximate Magnitude	Approximate TNT for Seismic Energy Yield	Joule equivalent	Example
8.35	50 megatons	210 PJ	Tsar Bomba - Largest thermonuclear weapon ever tested
8.5	85 megatons	360 PJ	M_W Sumatra earthquake (Indonesia), 2007
8.7	170 megatons	710 EJ	M_W Sumatra earthquake (Indonesia), 2005
8.75	200 megatons	840 PJ	Krakatoa 1883
8.8	240 megatons	1.0 EJ	M_W Chile earthquake, 2010,
9.0	480 megatons	2.0 EJ	M_W Lisbon earthquake (Portugal), All Saints Day, 1755 M_W Sendai earthquake and tsunami (Japan), 2011
9.15	800 megatons	3.3 EJ	Toba eruption 75,000 years ago; among the largest known volcanic events.[19]
9.2	950 megatons	4.0 EJ	M_W Anchorage earthquake (Alaska, USA), 1964 M_W Sumatra-Andaman earthquake and tsunami (Indonesia), 2004
9.5	2.7 gigatons	11 EJ	M_W Valdivia earthquake (Chile), 1960
10.0	15 gigatons	63 EJ	Never recorded
12.55	100 teratons	420 ZJ	Yucatán Peninsula impact (creating Chicxulub crater) 65 Ma ago (10^8 megatons; over 4×10^{30} ergs = 400 ZJ).[20][21][22][23][24]
32	1.5×10^{43} tons	6.3×10^{52} J	Approximate magnitude of the starquake on the magnetar SGR 1806-20, registered on

▶ Question: Is this accident a matter of residual risk of nuclear energy?

History data of earthquake-induced tsunamis with maximum amplitudes above 10 m hitting the coasts of Japan and the Kuril Islands (Russia) over the past 513 years					
Date and Country		Affected Region	Earthquake 1)	Tsunami 2)	Victims
11.03.2011	Japan	Japan	M = 9.0	23 m	> 10 000
04.10.1994	Russia	Kuril Islands	M = 8.3	11 m	Not specified
12.07.1993	Japan	Sea of Japan	M = 7.7	31.7 m	330
26.05.1983	Japan	Noshiro	M = 7.7	14.5 m	103
07.12.1944	Japan	Kii Peninsula	M = 8.1	10 m	40
02.03.1933	Japan	Sanriku	M = 8.4	30 m	3 000
01.09.1923	Japan	Tokaido	M = 7.9	12 m	2 144
07.09.1918	Russia	Kuril Islands	M = 8.2	12 m	50
15.06.1896	Japan	Sanriku	M = 7.6	38 m	26 360
24.12.1854	Japan	Nankaido	M = 8.4	28 m	3 000
29.06.1780	Russia	Kuril Islands	M = 7.5	12 m	12
24.04.1771	Japan	Ryukyu Islands	M = 7.4	85 m	13 500
28.10.1707	Japan	Japan	M = 8.4	11 m	30 000
31.12.1703	Japan	Tokaido-Kashima	M = 8.2	10,5 m	5 200
02.12.1611	Japan	Sanriku	M = 8.0	25 m	5 000
20.09.1498	Japan	Nankaido	M = 8.6	17 m	200

▶ **Simple Estimation:**

Within the past 513 years 16 tsunamis with maximum amplitudes above 10 m and induced by earthquakes of magnitudes between 7.4 and 9.2 have been recorded for Japan and the adjacent Kuril Islands (Russia).

▶ **Experienced Frequency:**

$f = 16/513\ a \approx 0.0312\ a^{-1}$

Thus, within a **thirty** years period one severe tsunami with a maximum amplitude of more than 10 m has to be expected in Japan!

Sources: Dr. Johannis Nöggerath, Swiss Nuclear Society, March 28, 2011, www.tsunami-alarm-system.com 1) magnitude 2) maximum amplitude

- **11 reactors were automatically shut-down**
  - Onagawa Unit 1,2,3
  - Fukushima Dai-ichi (I) Unit 1,2,3
  - Fukushima-Dai-ni (II) Unit 1,2,3,4
  - Tokai Dai-ni (II)

- **3 reactors were under periodic inspection**
  - Fukushima Dai-ichi (I) Unit 4,5,6

-After the automatic shut-down, the Unit 1-3 at Onagawa Nuclear Power Station, the Unit 3 at Fukushima II Nuclear Power Station, and the Unit at Tokai II Nuclear Power Station have been cold shut down safely.

-As for the unit 1,2,4 at Fukushima II Nuclear Power Station, the operator of the station reported NISA nuclear emergency situation because the temperature of the suppression pools became more than 100 °C, but afterward the three units have been cold shut down.

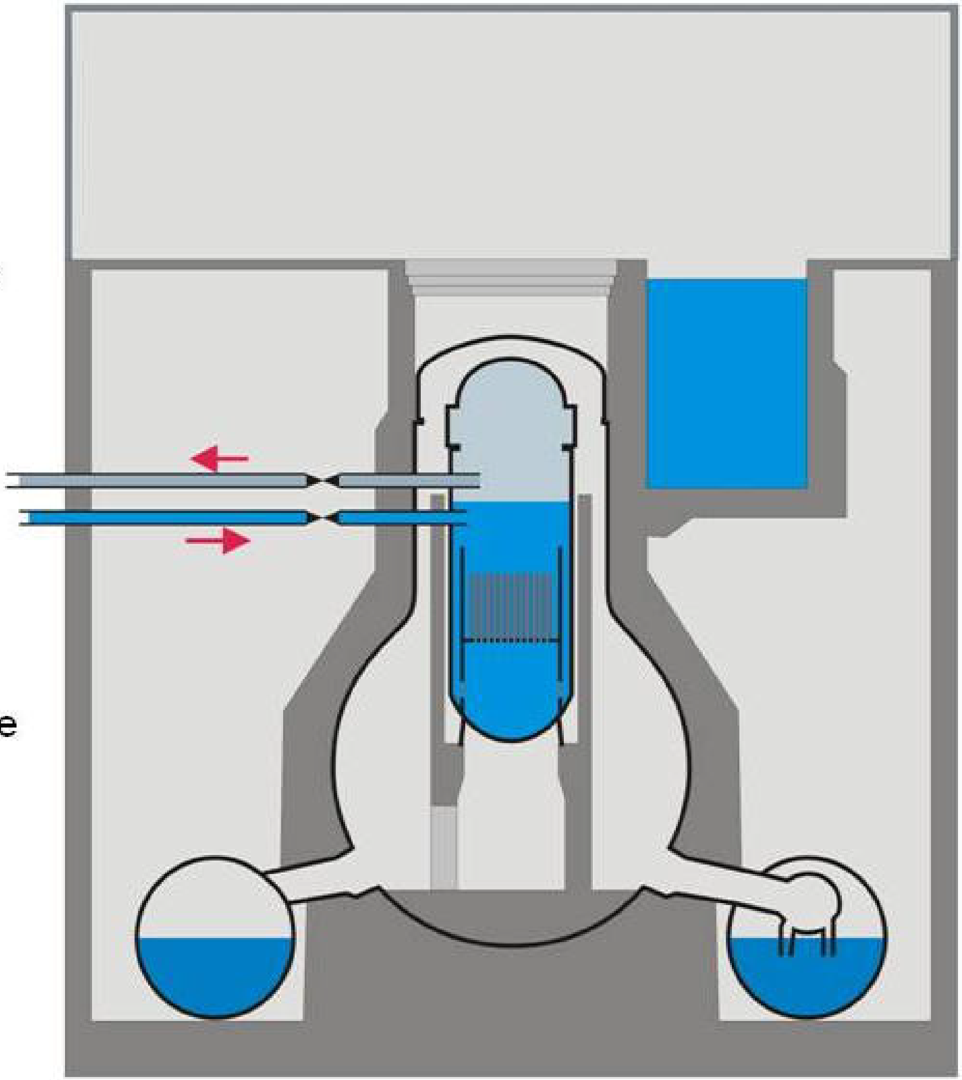
Plant Designs - Fukushima Dai-Ichi

- BWR is a Boiling Water Reactor
- Unit 1 is BWR/3
- Units 2-4 are BWR/4
- There are 56 Reactors in Japan (1-FBR, 4-ABWR, 29-BWR, 23-PWR) compared to 104 Reactors in the USA (35 BWRs & 69 PWRs)
- The Fukushima I reactors began operation in the 1970's so they are all thirty - forty years old.
- Fukushima I Units 1-4 all are early vintage Mark I Containment Designs

- The plant was immediately shut down (scrammed) when the earthquake first hit. Off-Site power was lost.
- Emergency Diesel Generators (EDGs) started to provide backup electrical power to the plant's backup cooling system. The backup emergency systems worked.
- All AC power to the station was lost when the tsunami flooded the EDGs, which occurred about 1 hour after the earthquake.
- At that point, the plant experienced a complete blackout (no AC electric power at all). Commonly called a "Station Blackout".
- Only battery power was left.

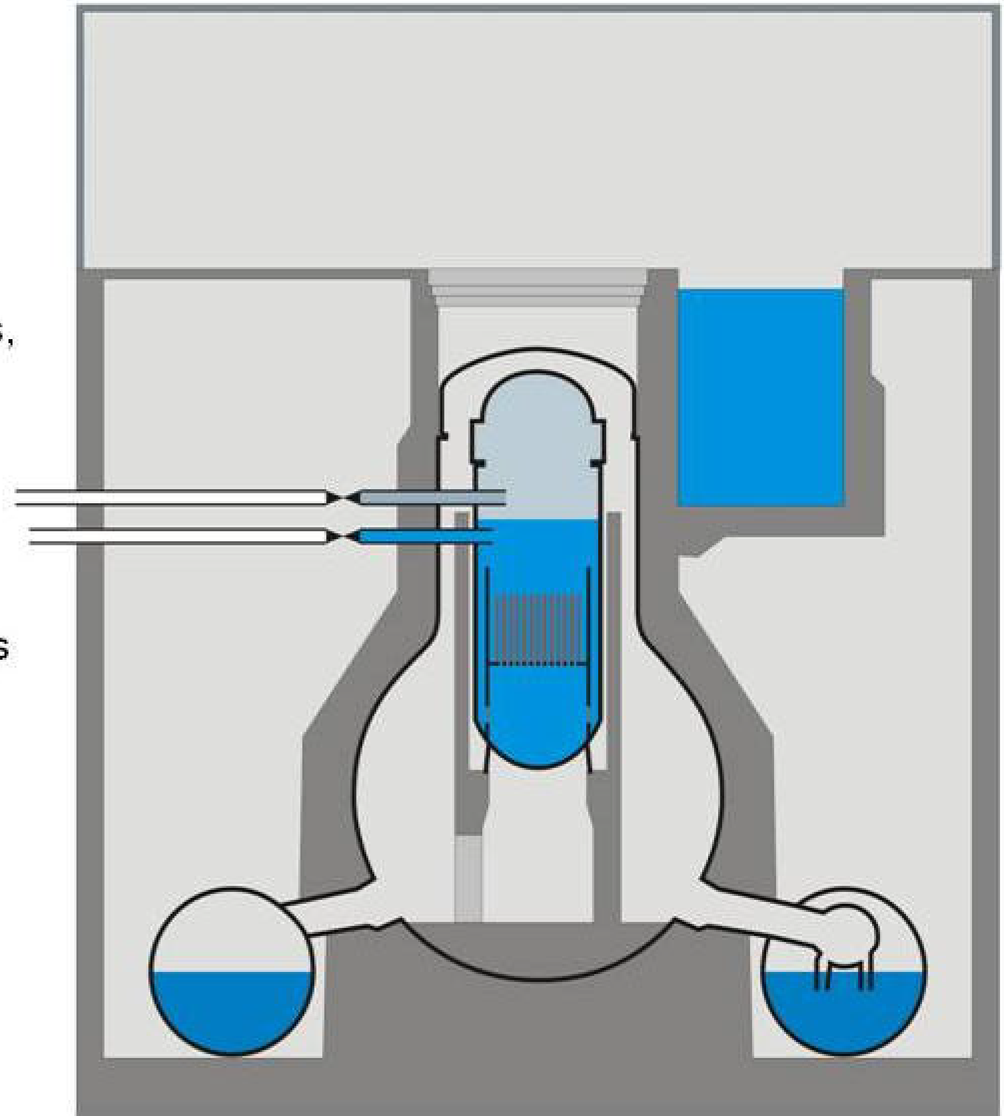
When it Started

- 11.3.2011 14:46 - Earthquake
  - Magnitude 9
  - Power grid in northern Japan fails
  - Reactors itself are mainly undamaged
- SCRAM
  - Power generation due to Fission of Uranium stops
  - Heat generation due to radioactive Decay of Fission Products
    - After Scram ~6%
    - After 1 Day ~1%
    - After 5 Days ~0.5%



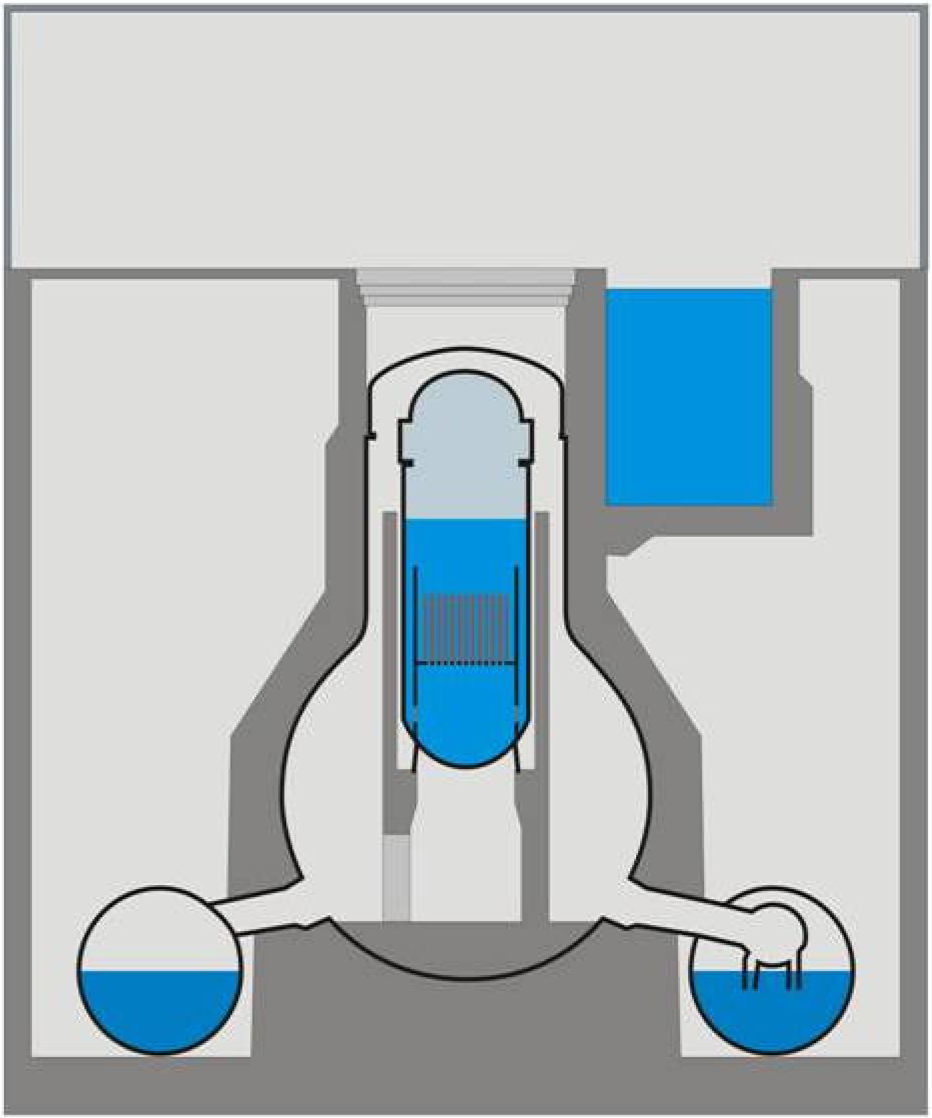
Containment Isolation

- Containment Isolation
  - Closing of all non-safety related Penetrations of the containment
  - Cuts off Machine hall
  - If containment isolation succeeds, a large early release of fission products is highly unlikely
- Diesel generators start
  - Emergency Core cooling systems are supplied
- Plant is in a stable safe state



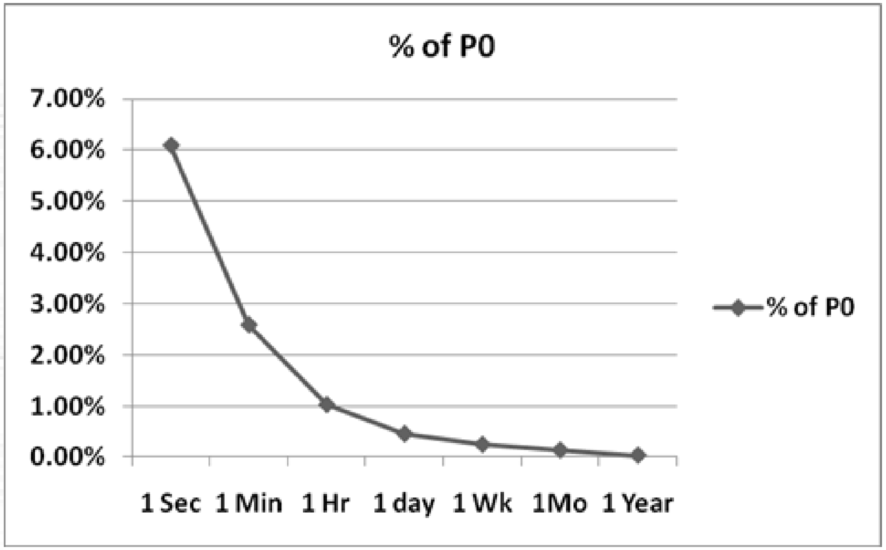
The Tsunami Hits

- 11.3. 15:41 Tsunami hits the plant
  - Plant Design for Tsunami height of up to 6.5m
  - Actual Tsunami height >7m
  - Flooding of
    - Diesel Generators and/or
    - Essential service water building cooling the generators
- Station Blackout
  - Common cause failure of the power supply
  - Only Batteries are still available
  - Failure of all but one Emergency core cooling systems

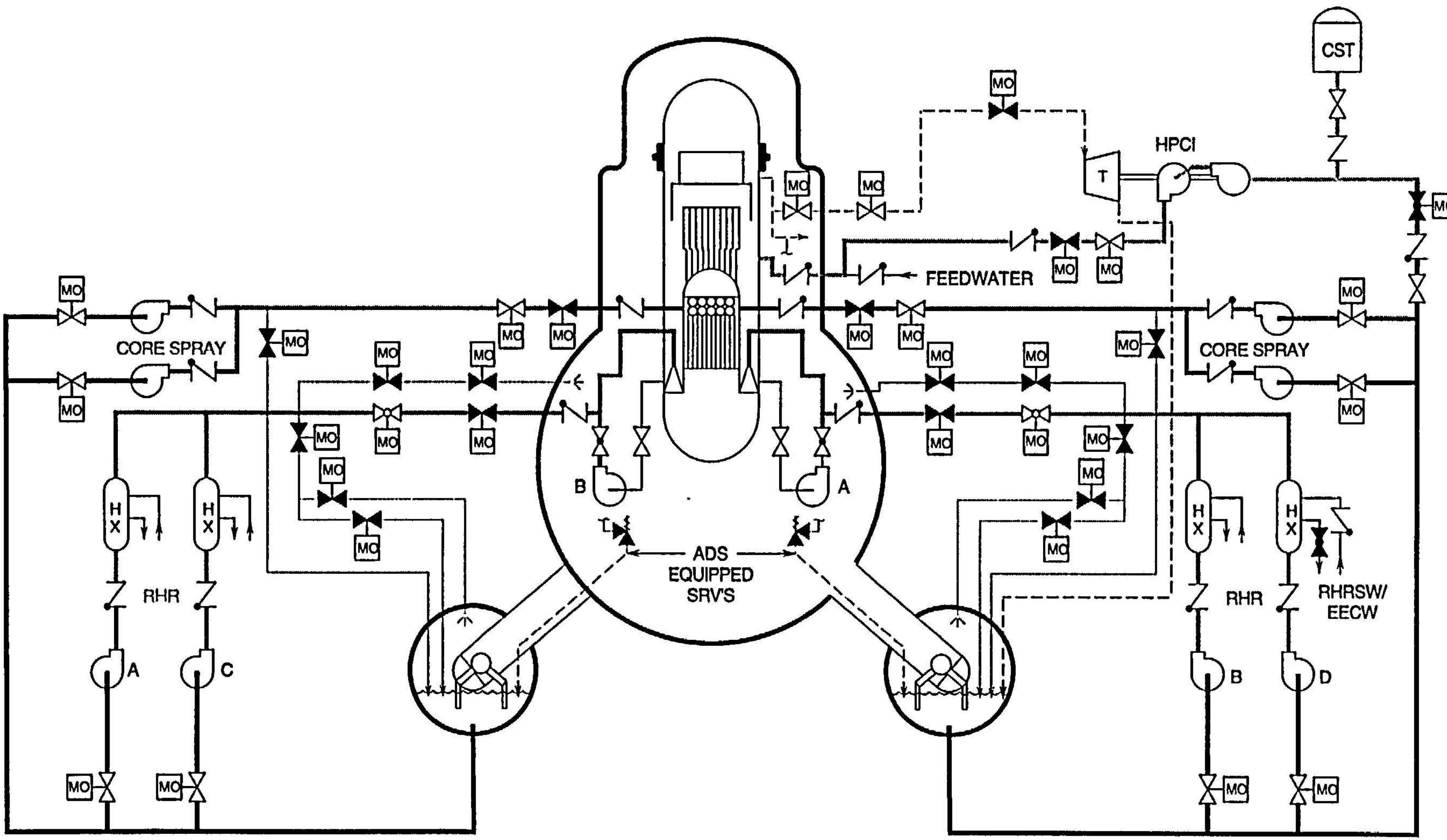


t	% of P_0	P(t), MWt	% of P_0 ANS 5.1
1 Sec	6.09%	140.17	6.03%
1 Min	2.58%	59.24	3.65%
1 Hr	1.02%	23.56	2.46%
1 day	0.45%	10.33	1.00%
1 Wk	0.24%	5.54	0.58%
1 Mo	0.13%	3.04	0.38%
1 Year	0.03%	0.59	0.20%

* Based on 2301 MWt (760 MWe)



Typical ECCS for BWR/3 & /4



•Initially the isolation condenser (IC) for Unit 1, which uses the CST water as a heat sink, was used to remove the decay heat from the shutdown reactor. After 1 or 2 hours, the 26,000 gallons of water in the IC is boiling, the CST water was not available and no heat removal other than IC boiling was available for Unit 1.

•Boiling began in the suppression pool and the drywell pressure began to increase in about 11 hours after the SBO.

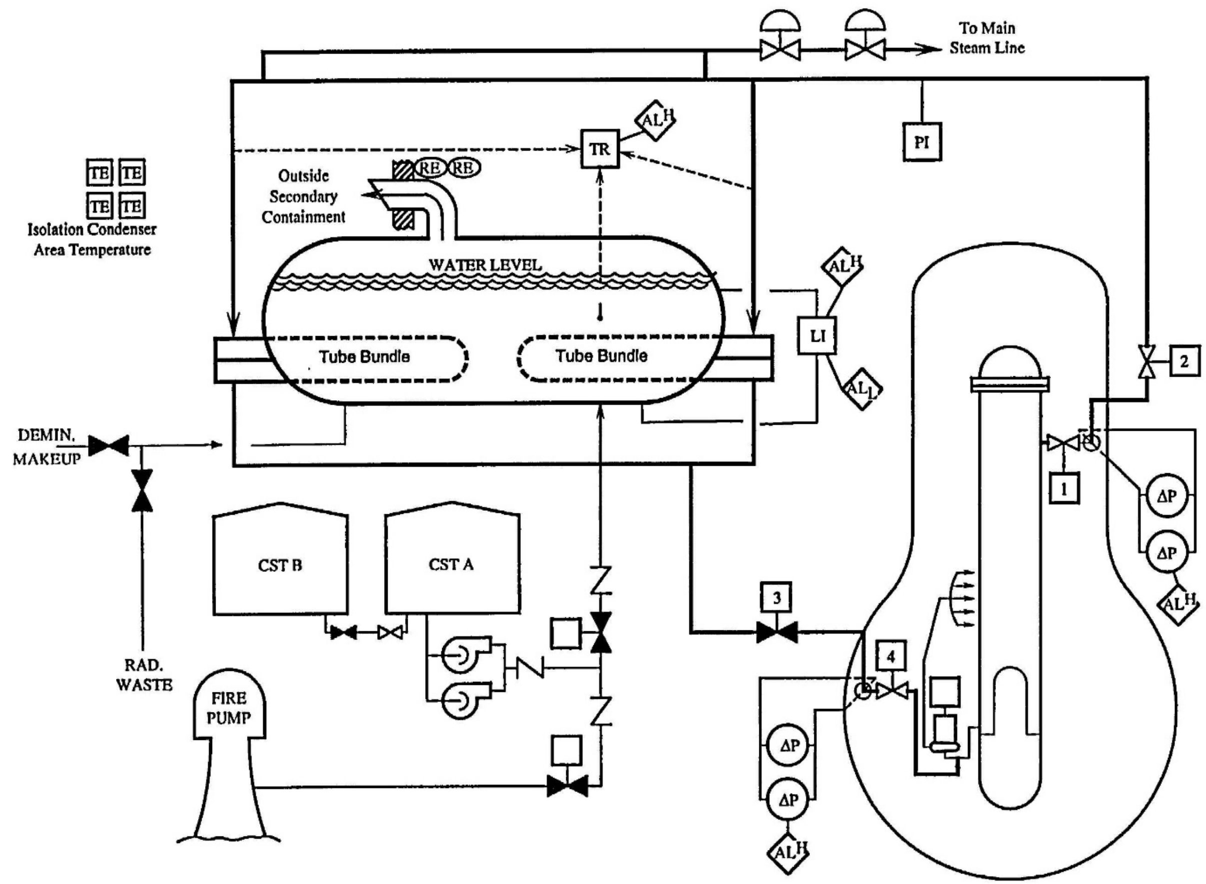
•In about 16 hours the water level in the core began to decrease and core degradation occurred (through some combination of zirconium oxidation and clad failure).

•Venting occurred at about 23 hours after SBO and the hydrogen explosion occurred in the RB about 1 hour later.

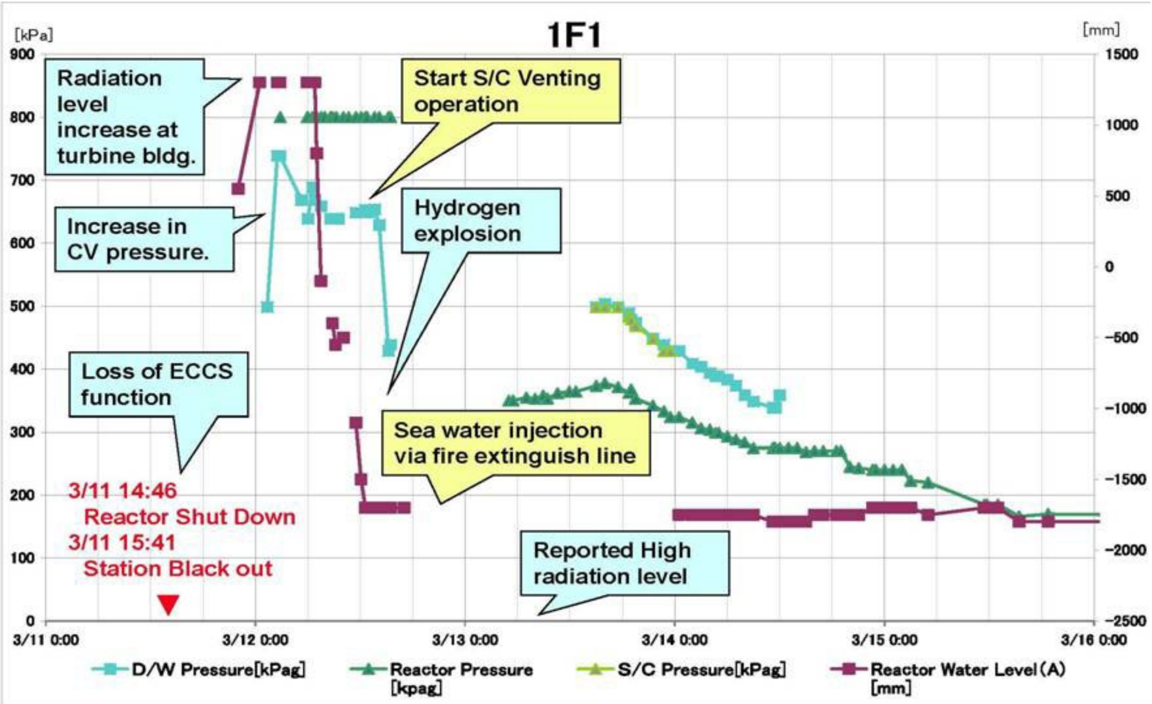
•Sea water was injected into the core at about 31 hours after SBO.

Unit 1 Cooled with Isolation Condenser for 4-12 Hours

- Draws steam from main steam line via natural circulation and returns to recirculation suction line.
- Tank is 55 feet long, 12 feet in diameter
- 26,000 gallon tank
- Make-up to IC tank is from CST via AC pumps
- W/O AC, water in tank is an effective coolant for about 2-6 hours



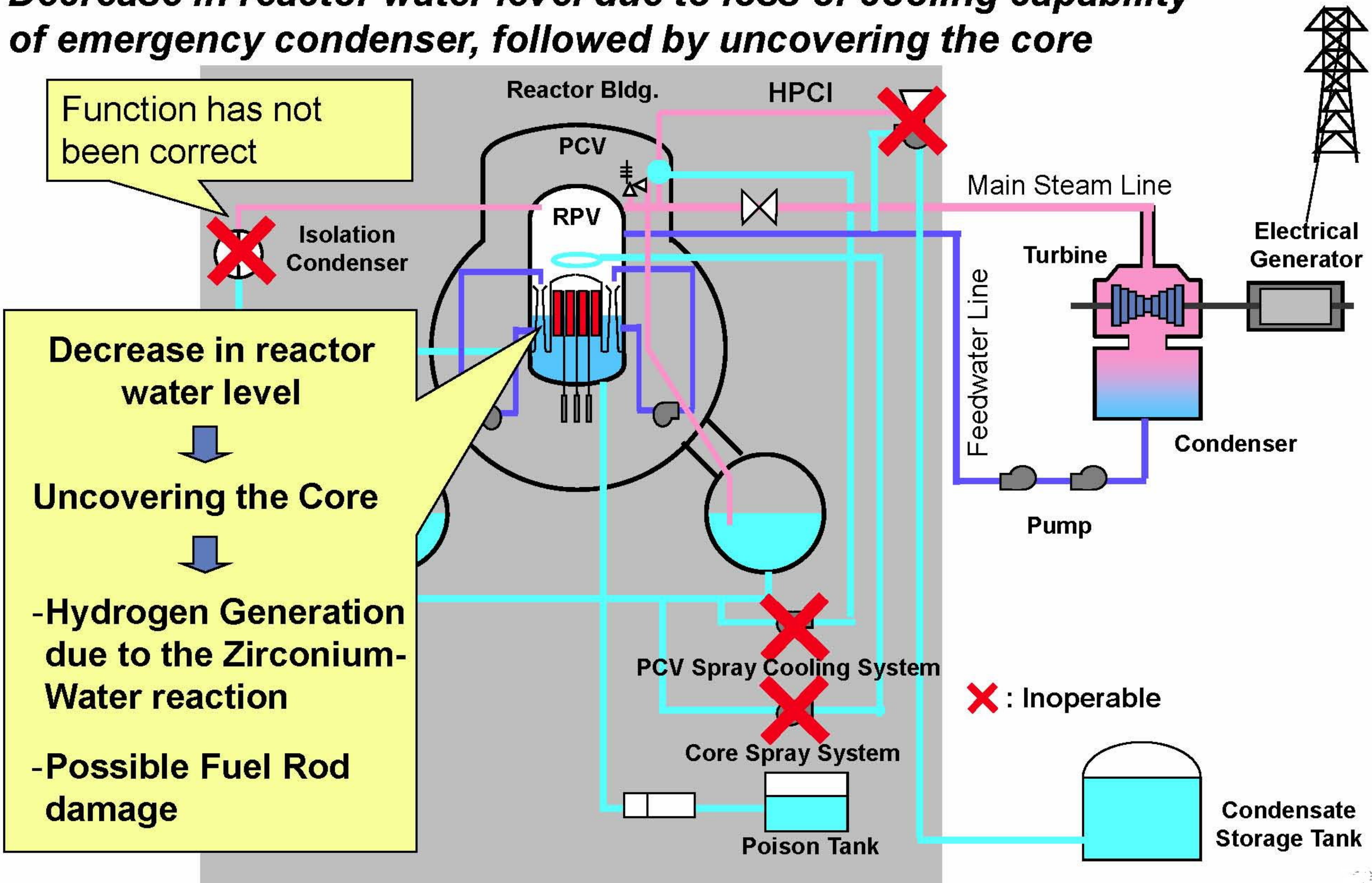
Unit 1 Primary Containment Pressure (D/W) & Reactor Pressure (3/11 – 3/16)



Unit 1 Major Early Events		
Event	**Time Occurred***	**Time Duration from Earthquake**
Earthquake	3/11 14:46	0 hour
Tsunami/SBO	3/11 15:41	55 minutes
IC Start	3/11 16:41	1 Hour 55 minutes
IC Lost	3/12 01:46	11 hours
Pressure rises in DW to 740kPa (107psi)	3/12 02:30	11 hours 44 minutes
Reactor Water Level Drops	3/12 07:00	16 hours 14 minutes
Venting Begins	3/12 14:30	23 hours 44 minutes
H2 Explosion in RB	3/12 15:36	24 hours 50 minutes
Sea Water Injection Begins	3/12 22:00	31 hours 14 minutes

* approximate time

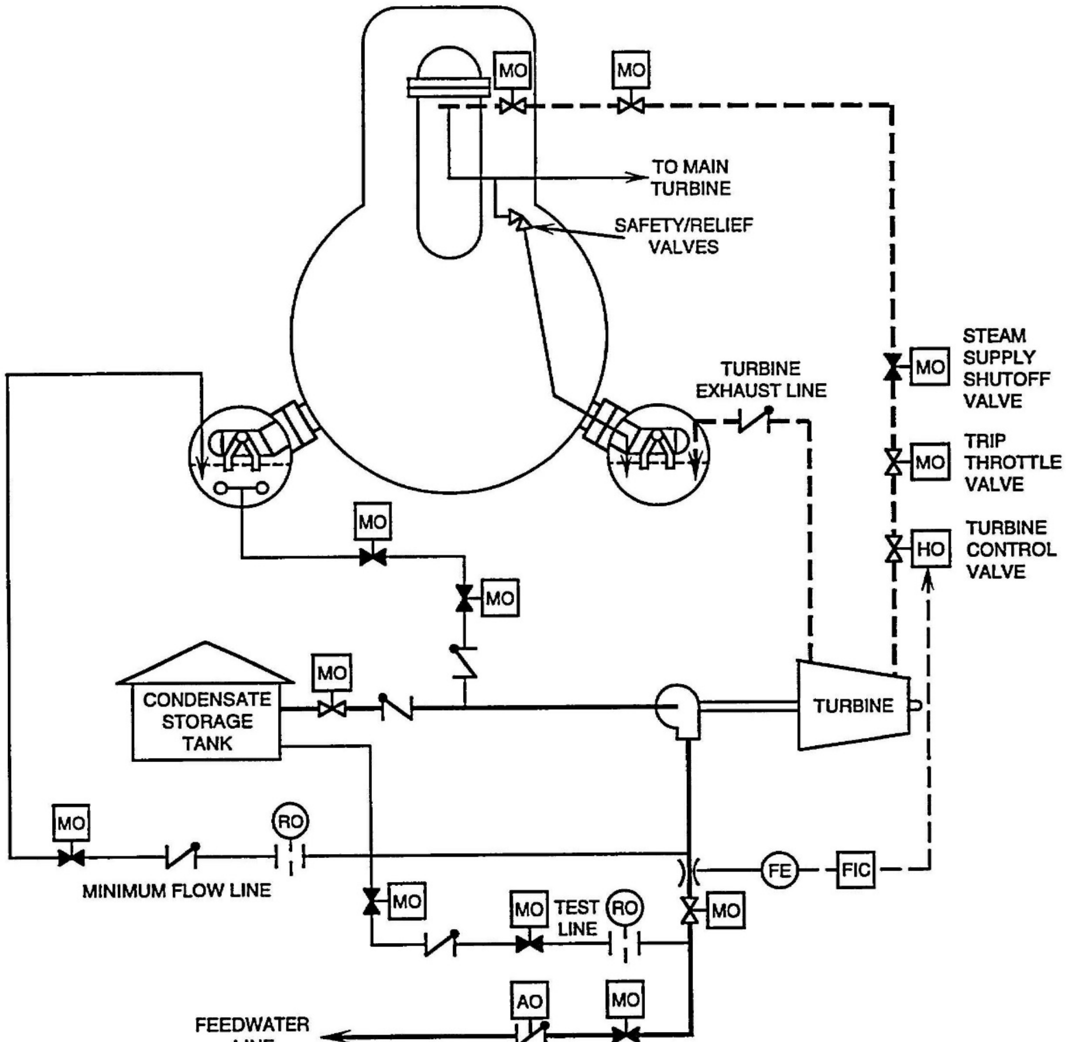
Decrease in reactor water level due to loss of cooling capability of emergency condenser, followed by uncovering the core



BYU 1875 BRIGHAM YOUNG UNIVERSITY PROVO, UTAH

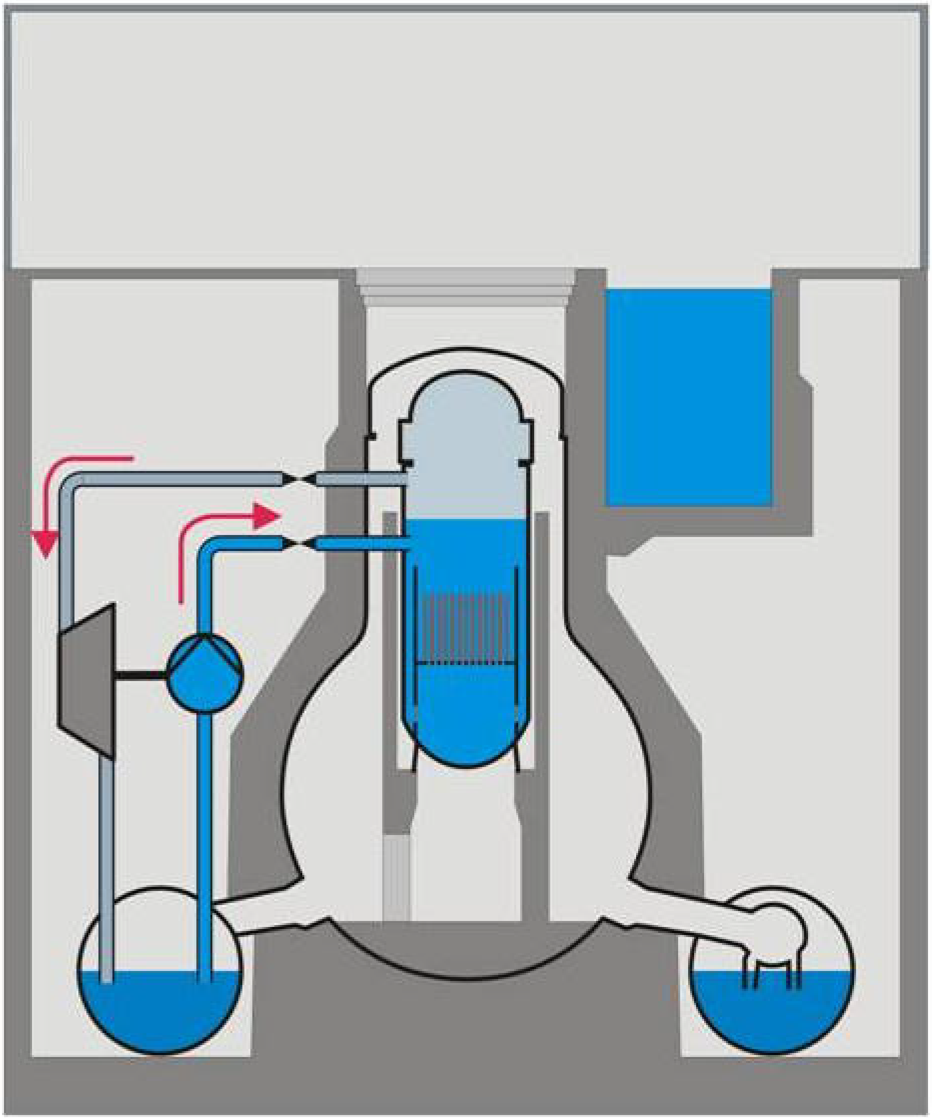
•Turbine Driven Reactor Core Isolation Cooling (RCIC) system for Unit 2, which operates on steam from the reactor.
•The RCIC turbine drives a pump using make-up water from the wet well or CST
•High Pressure Coolant Injection (HPCI) wasn't used or did not work for Unit 2
•DC power from batteries and/or the use of DC powered pumps were lost after 70 hours, which is phenomenal considering that they are only designed to last 8 hours.
•Although sea water was injected within an hour after the loss of RCIC, it appears that water level continued to decrease in the RV and DW pressure increased. Significant pressure increases were observed in the RV.
•No venting of the DW was observed
•DW pressure stayed high on 3/15 00:00 and an explosion was heard in the lower part of the reactor building.
•It is believed that the primary containment was damaged.

Units 2&3 Cooled with reactor core isolation cooling (RCIC) for Unit 2 (66

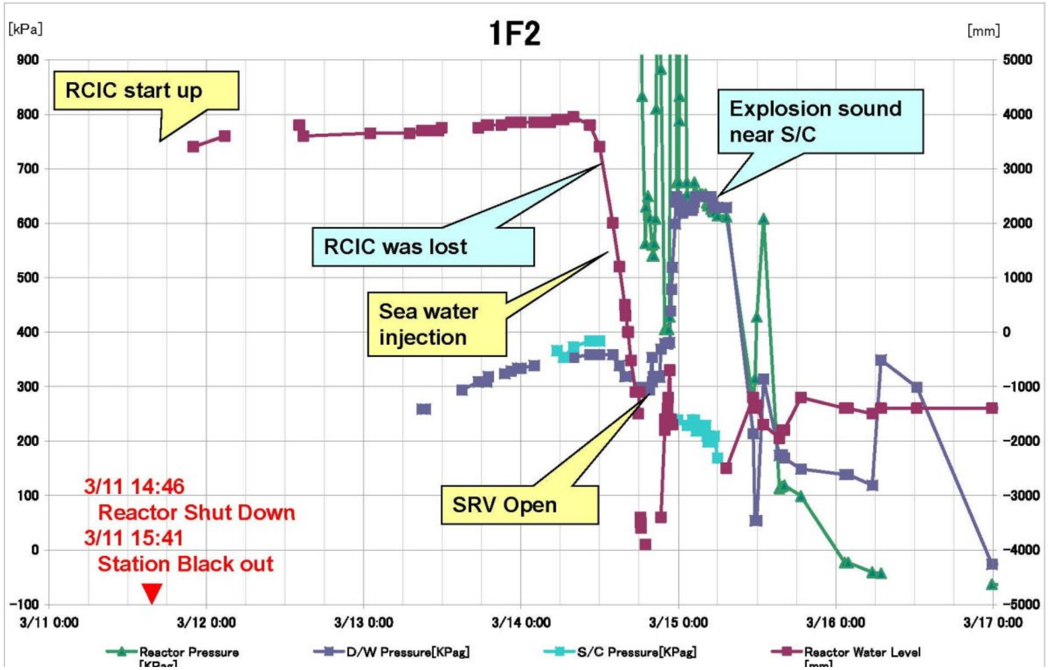


Isolation Condenser (Unit 1) and RCIC (Units 2 & 3) Were Used to Cool the Plants

- Reactor Core Isolation Pump still available
  - Steam from the Reactor drives a Turbine
  - Steam gets condensed in the Wet-Well
  - Turbine drives a Pump
  - Water from the Wet-Well gets pumped in Reactor
  - Necessary:
    - Battery power
    - Temperature in the wet-well must be below 100°C
- As there is no heat removal from the building, the Core isolation pump can't work infinitely



Unit 2 Primary Containment Pressure (D/W) & Reactor Pressure (3/11 – 3/17)

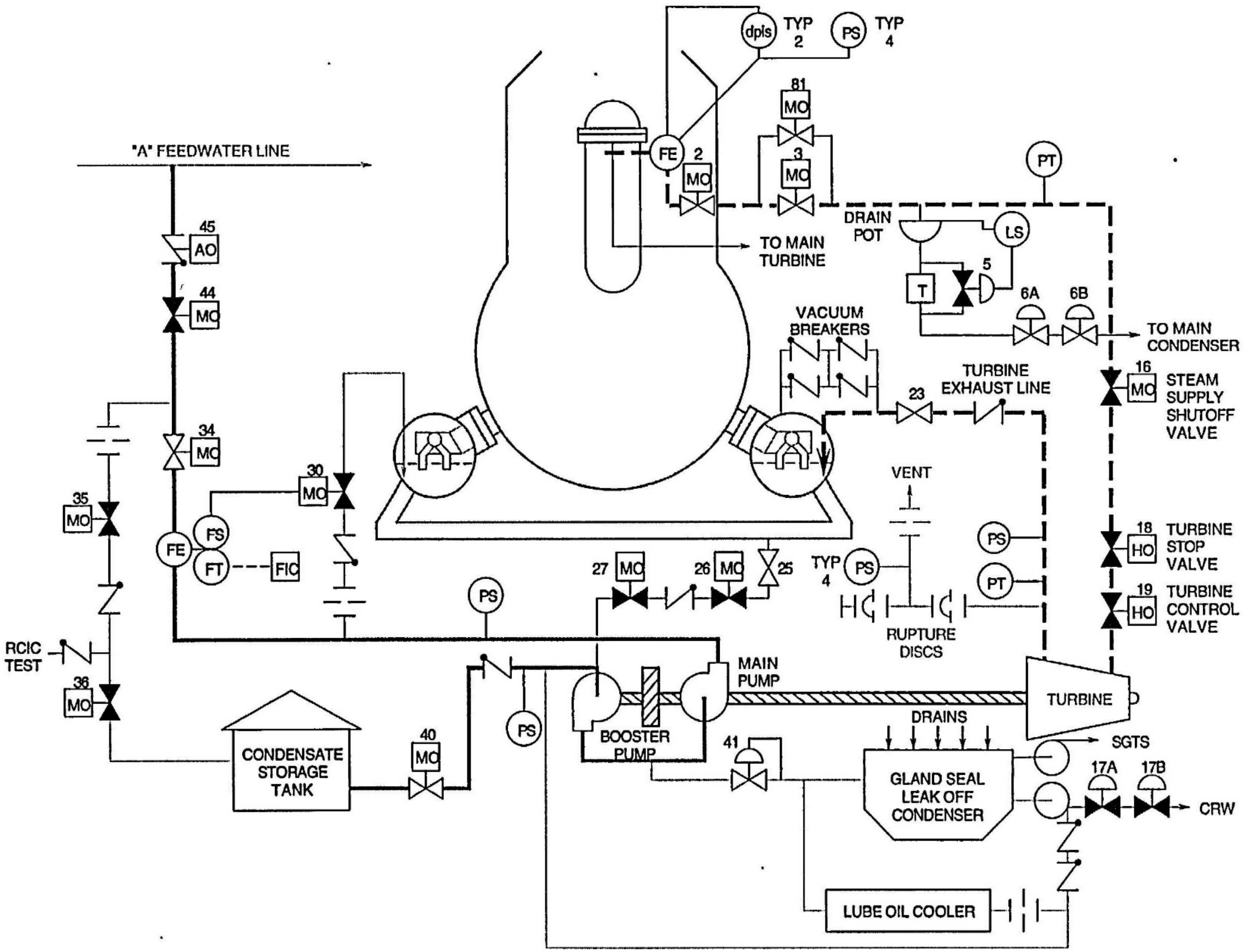


Unit 2 Major Early Events		
Event	**Time Occurred***	**Time Duration from Earthquake**
Earthquake	3/11 14:46	0 hour
Tsunami/SBO	3/11 15:41	55 minutes
RCIC Start	3/11 17:30	3 Hours 16 minutes
RCIC Lost	3/14 13:25	70 hours 39 Min
Sea Water Injection Begins	3/14 14:00	71 hours 14 min
SRV Opens	3/14 20:00	77 hours 14 min
Reactor Pressure Pikes	3/14 18:00 to 3/15 02:00	75 hours 14 minutes to 83 hours 14 minutes
DW Pressure Rises to 650 kPa(94 psi)	3/15 0:00	81 hours 14 minutes
Explosion near torus	3/15 06:00	87 hours 14 minutes
DW Pressure fall to low level	3/15 12:00	93 hours 14 minutes

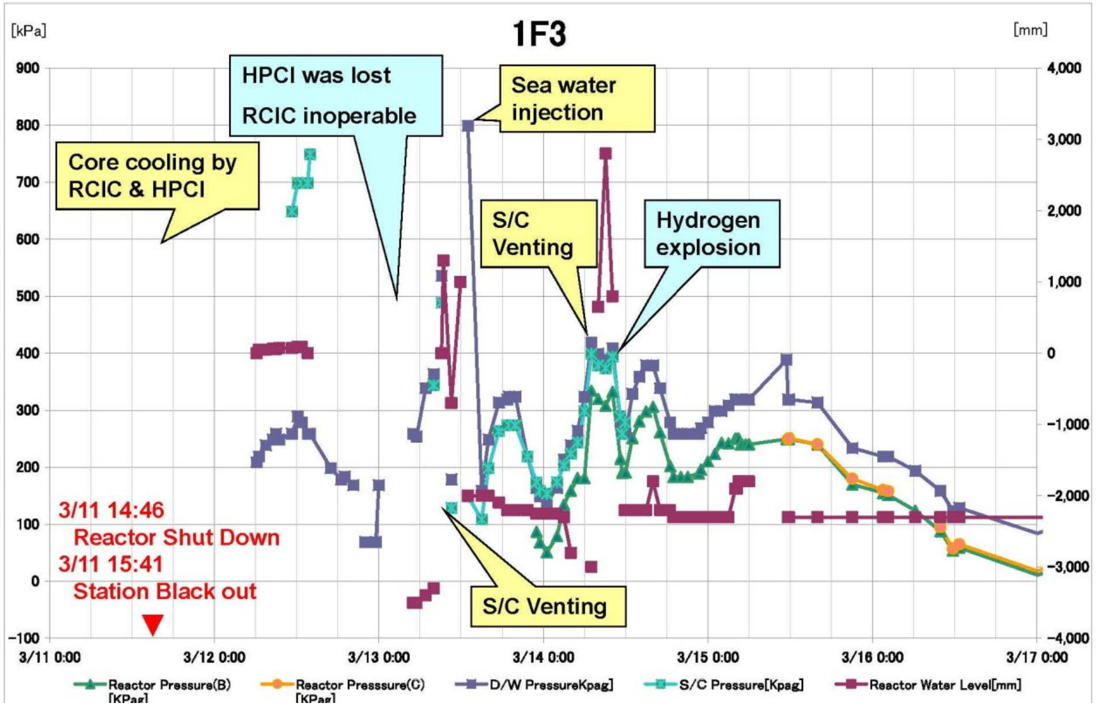
* approximate time

- Turbine Driven Reactor Core Isolation Cooling (RCIC) and High Pressure Coolant Injection (HPCI) systems were used to cool Unit 3. Steam from the reactor turns a turbine that powers a pump to send make-up water from the wet well or CST to the reactor.
- DC power from batteries and/or use of DC powered pumps were lost after 35 hours (half the time when using only RCIC system for Unit 2), which is great considering that they are only designed to last 8 hours.
- Sea water was injected within 6 hours after the loss of RCIC & HPCI, and it appears that water level continued to decrease in the RV and DW pressure increased. Core damaged was assumed to occur during this time period.
- Venting of the DW was observed at 43 hours and at 64 hours after SBO.
- An explosion in the top of the reactor building occurred 4 hours after second venting began.

Unit 3 Cooled with RCIC and high pressure coolant injection (HPCI) for 35



Unit 3 Primary Containment Pressure (D/W) & Reactor Pressure (3/11 – 3/17)



Unit 3 Major Early Events		
Event	**Time Occurred***	**Time Duration from Earthquake**
Earthquake	3/11 14:46	0 hour
Tsunami/SBO	3/11 15:41	55 minutes
RCIC & HPCI Start	3/11 16:46	2 Hours
RCIC & HPCI Lost	3/13 02:46	36 hours
DW Venting	3/13 09:00	42 hours 14 minutes
Sea Water Injection Begins	3/13 14:00	47 hours 14 minutes
DW Venting	3/14 06:46	64 hours
H2 Explosion in RB	3/14 10:46	68 hours

* approximate time

Unit 1 Major Early Events(IC Used to Cool)		
Event	**Time Occurred***	**Time Duration from Earthquake**
Earthquake	3/11 14:46	0 hour
Tsunami/SBO	3/11 15:41	55 minutes
IC Start	3/11 16:41	1 Hour 55 minutes
IC Lost	3/12 01:46	11 hours
Pressure rises in DW to 740kPa (107psi)	3/12 02:30	11 hours 44 minutes
Reactor Water Level Drops	3/12 07:00	16 hours 14 minutes
Venting Begins	3/12 14:30	23 hours 44 minutes
H2 Explosion in RB	3/12 15:36	24 hours 50 minutes
Sea Water Injection Begins	3/12 22:00	31 hours 14 minutes

* approximate time

Unit 2 Major Early Events (RCIC Used to Cool, Suction from CST?)		
Event	**Time Occurred***	**Time Duration from Earthquake**
Earthquake	3/11 14:46	0 hour
Tsunami/SBO	3/11 15:41	55 minutes
RCIC Start	3/11 17:30	3 Hours 16 minutes
RCIC Lost	3/14 13:25	70 hours 39 Min
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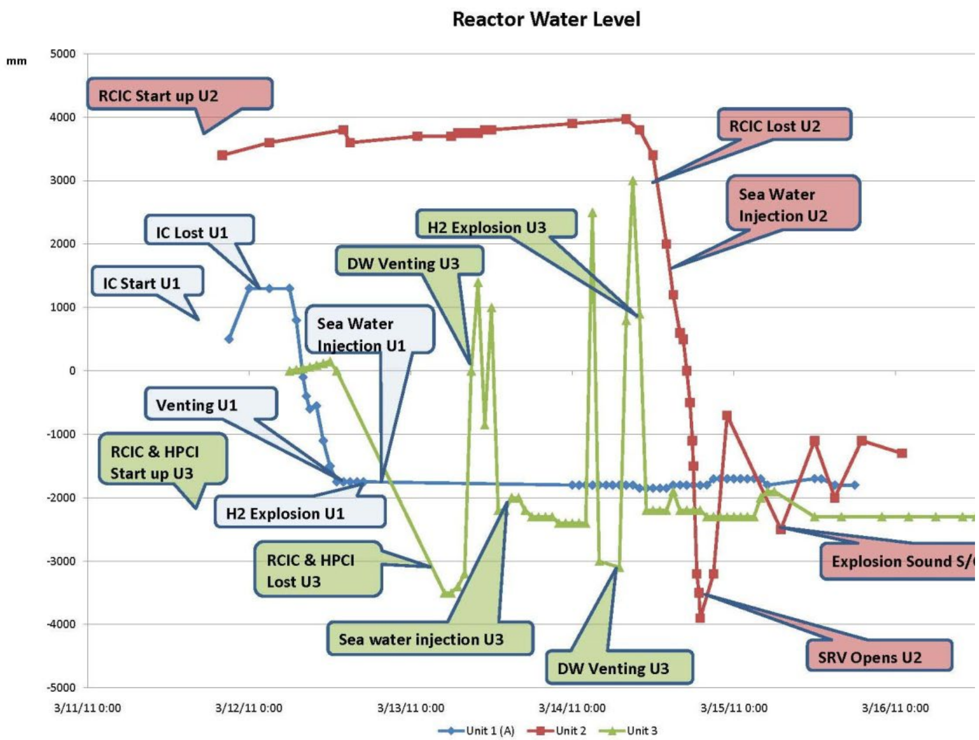
Reactor Pressure Pikes	3/14 18:00 to 3/15 02:00	75 hours 14 minutes to 83 hours 14 minutes
DW Pressure Rises to 650 kPa(94 psi)	3/15 0:00	81 hours 14 minutes
Explosion near torus	3/15 06:00	87 hours 14 minutes
DW Pressure fall to low level	3/15 12:00	93 hours 14 minutes

* approximate time

Unit 3 Major Early Events (RCIC & HPCI Used to Cool)		
Event	**Time Occurred***	**Time Duration from Earthquake**
Earthquake	3/11 14:46	0 hour
Tsunami/SBO	3/11 15:41	55 minutes
RCIC & HPCI Start	3/11 16:46	2 Hours
RCIC & HPCI Lost	3/13 02:46	36 hours
DW Venting	3/13 09:00	42 hours 14 minutes
Sea Water Injection Begins	3/13 14:00	47 hours 14 minutes
DW Venting	3/14 06:46	64 hours
H2 Explosion in RB	3/14 10:46	68 hours

* approximate time

Units 1, 2 & 3 Water Level



Unit 1 Major Early Events(IC Used to Cool)		
Event	**Time Occurred***	**Time Duration from Earthquake**
Earthquake	3/11 14:46	0 hour
Tsunami/SBO	3/11 15:41	55 minutes
IC Start	3/11 16:41	1 Hour 55 minutes
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Explosion near torus	3/15 06:00	87 hours 14 minutes
DW Pressure fall to low level	3/15 12:00	93 hours 14 minutes

* approximate time

Unit 3 Major Early Events (RCIC & HPCI Used to Cool)		
Event	**Time Occurred***	**Time Duration from Earthquake**
Earthquake	3/11 14:46	0 hour
Tsunami/SBO	3/11 15:41	55 minutes
RCIC & HPCI Start	3/11 16:46	2 Hours
RCIC & HPCI Lost	3/13 02:46	36 hours
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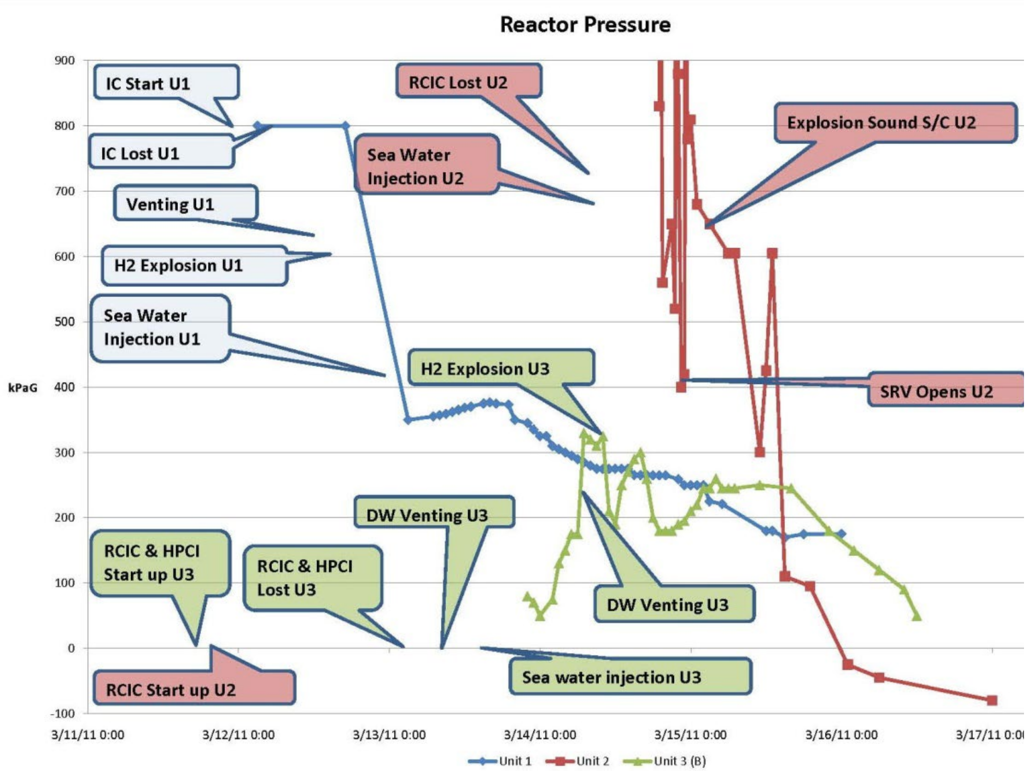
Sea Water Injection Begins	3/13 14:00	47 hours 14 minutes
DW Venting	3/14 06:46	64 hours
H2 Explosion in RB	3/14 10:46	68 hours

* approximate time

Units 1, 2 & 3 Reactor Pressure



Unit 1 Major Early Events(IC Used to Cool)		
Event	Time Occurred*	Time Duration from Earthquake
Earthquake	3/11 14:46	0 hour
Tsunami/SBO	3/11 15:41	55 minutes
IC Start	3/11 16:41	1 Hour 55 minutes
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DW Pressure fall to low level	3/15 12:00	93 hours 14 minutes

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Unit 3 Major Early Events (RCIC & HPCI Used to Cool)		
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Earthquake	3/11 14:46	0 hour
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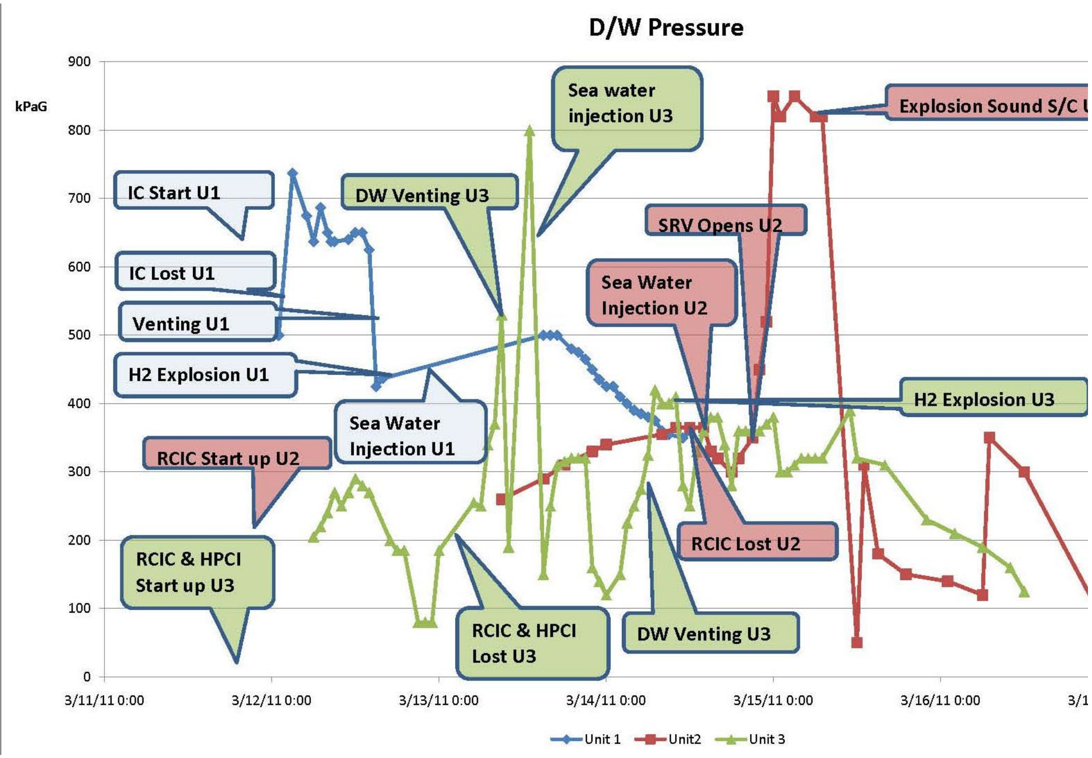
DW Venting	3/14 06:46	64 hours
H2 Explosion in RB	3/14 10:46	68 hours

* approximate time

Units 1, 2 & 3 Drywell Pressure



Unit 1 Major Early Events(IC Used to Cool)		
Event	**Time Occurred***	**Time Duration from Earthquake**
Earthquake	3/11 14:46	0 hour
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Unit 2 Major Early Events (RCIC Used to Cool, Suction from CST?)		
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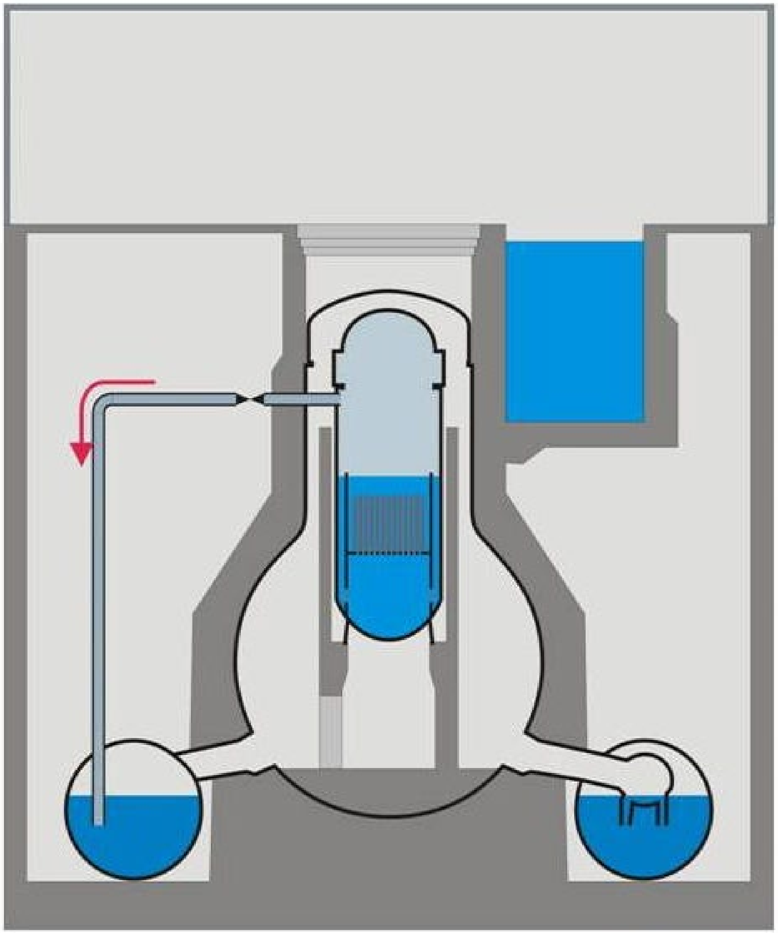
DW Venting	3/14 06:46	64 hours
H2 Explosion in RB	3/14 10:46	68 hours

* approximate time

RCIC Works for about 66 Hours (Unit 2) and 34 Hours (Unit 3)

- RCIC Pumps Stop
  - 3/14 13:25 in Unit 2
  - 3/13 2:46 in Unit 3
- Decay Heat Causes the water to boil in the reactor Vessel and the pressure rises in the Reactor Vessel.
- The steam is released into the wet-wet through the SRVs
- Since there is no make up, the water level falls in the reactor vessel

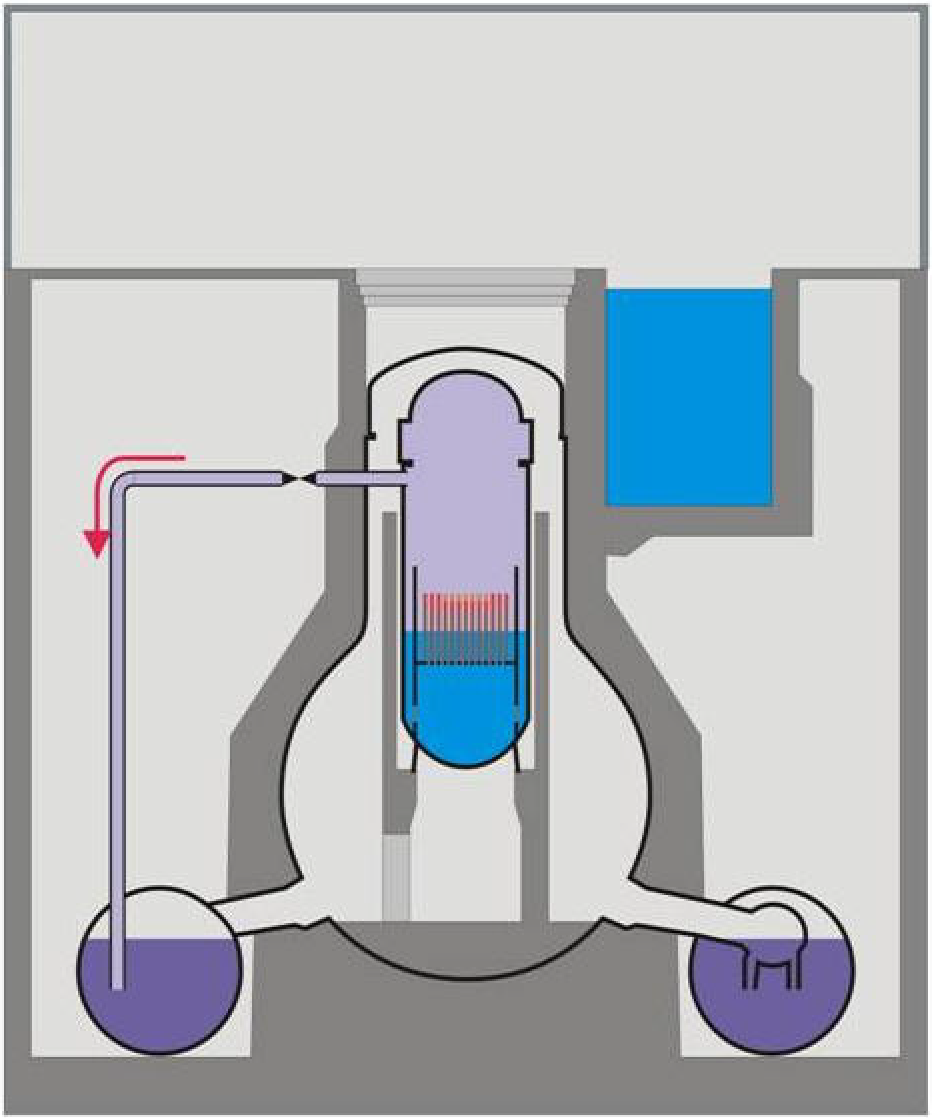


Fuel in Top of Core is Uncovered

- Measured, and here referenced Liquid level is the collapsed level. The actual liquid level lies higher due to the steam bubbles in the liquid

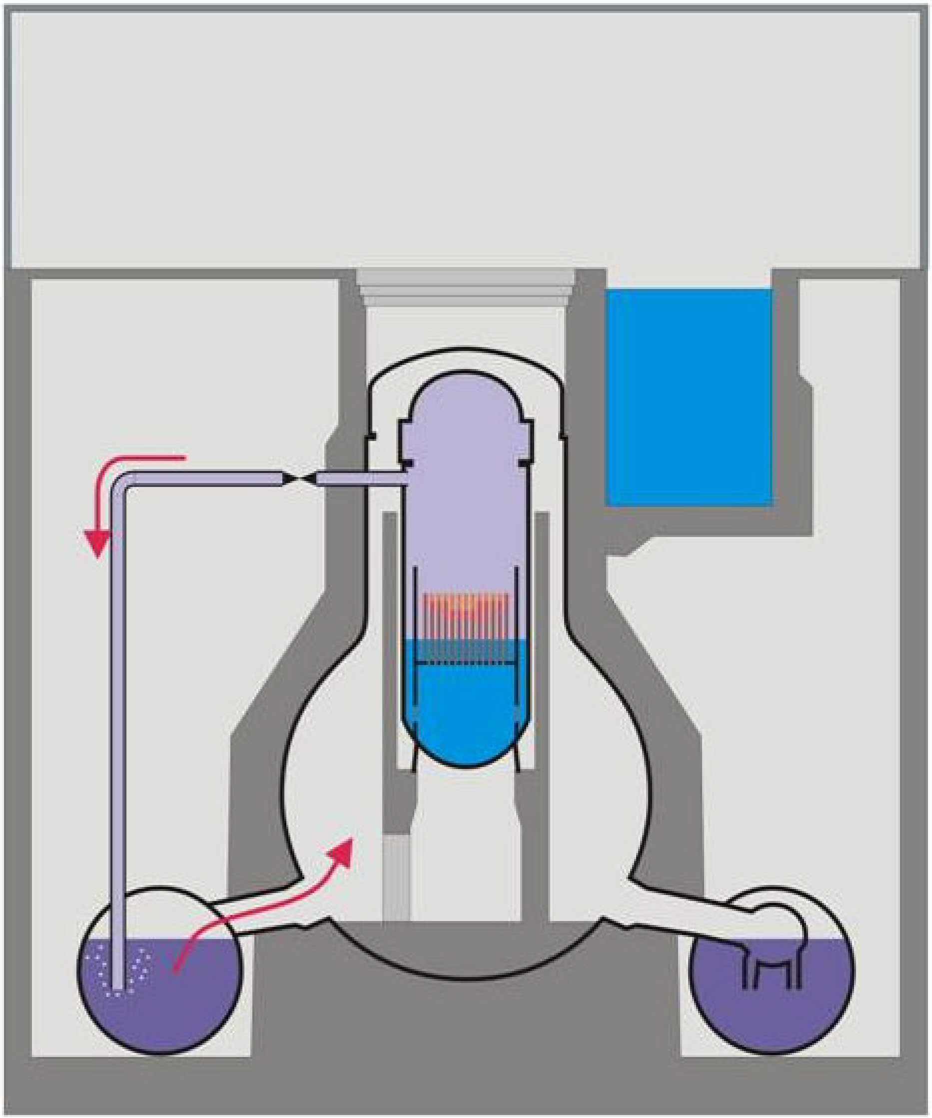
- ~50% of the core exposed
  - Cladding temperatures rise, but still no significant core damage

- ~2/3 of the core exposed
  - Cladding temperature exceeds ~900°C
  - Balooning / Breaking of the cladding
  - Release of fission products form the fuel rod gaps



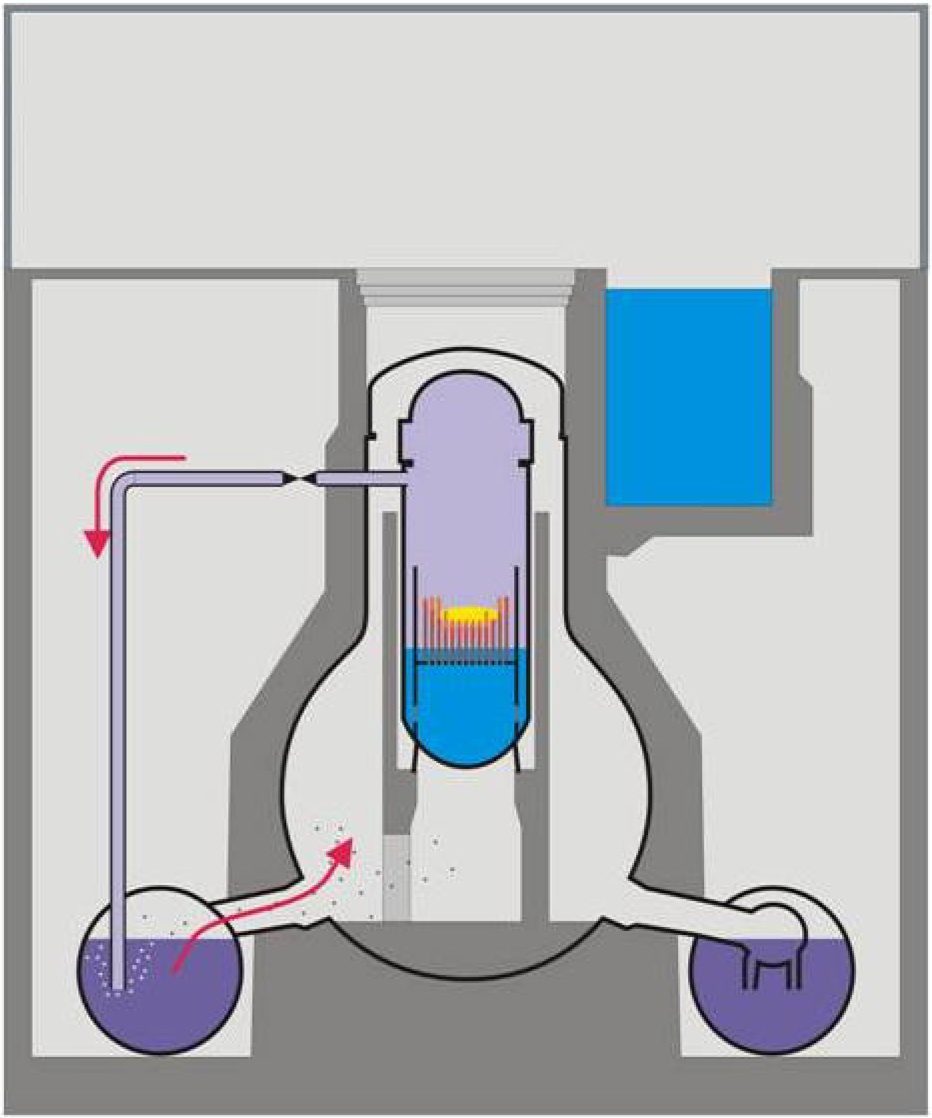
Zr-Water Begins at

- ~3/4 of the core exposed
  - Cladding exceeds ~1200°C
  - Zirconium in the cladding starts to burn under Steam atmosphere
  - **$Zr + 2H_20 \rightarrow ZrO_2 + 2H_2$**
  - Exothermal reaction further heats the core
  - Generation of hydrogen
    - Unit 1: 300-600kg
    - Unit 2/3: 300-1000kg
  - Hydrogen gets pushed via the wet-well and wet-well vacuum breakers into the dry-well



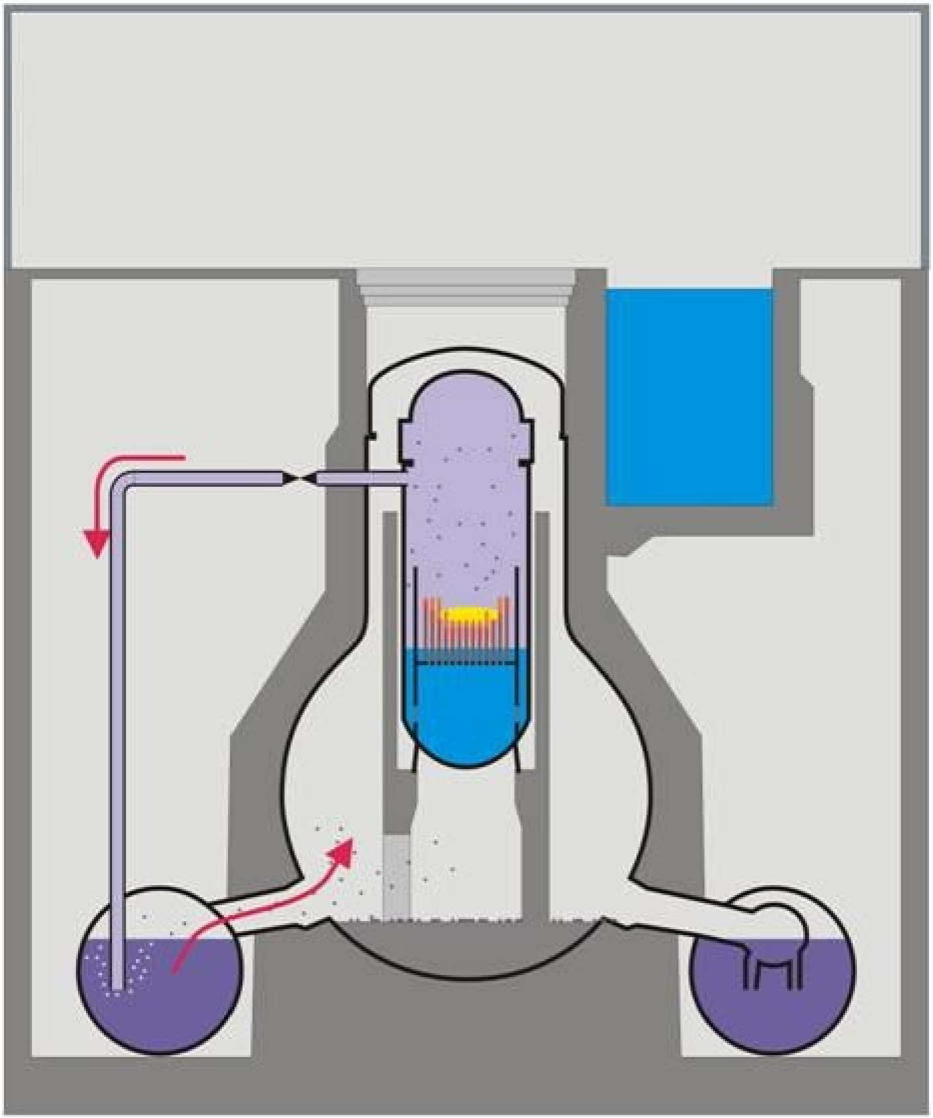
Release of Fission Products

- Release of fission products during melt down
  - Xenon, Cesium, Iodine,...
  - Uranium/Plutonium remain in core
  - Fission products condensate to airborne Aerosols
- Discharge through valves into water of the condensation chamber
  - Pool scrubbing binds a fraction of Aerosols in the water
- Xenon and remaining aerosols enter the Dry-Well
  - Deposition of aerosols on surfaces further decontaminates air



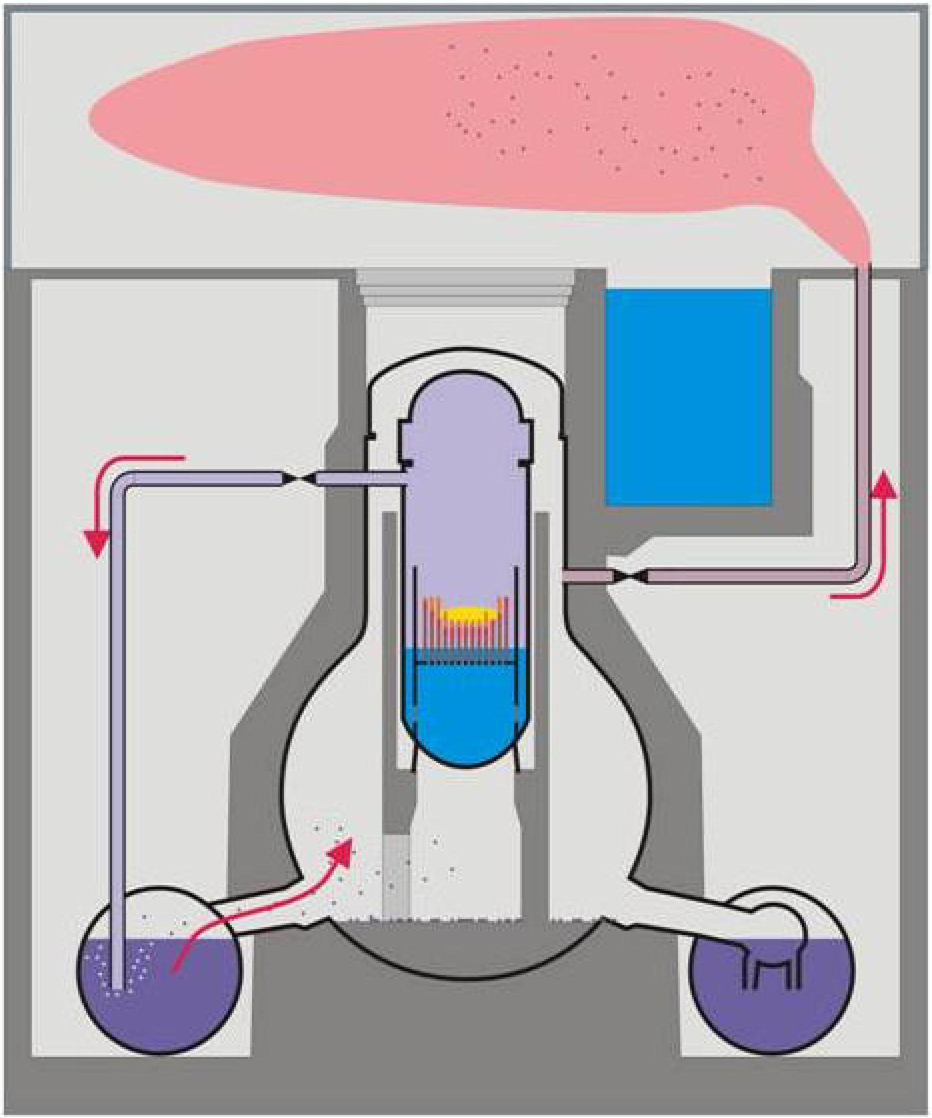
Containment is Last Barrier

- Containment
  - Last barrier between Fission Products and Environment
  - Wall thickness ~3cm
  - Design Pressure 4-5bar
- Actual pressure up to 8 bars
  - Normal inert gas filling (Nitrogen)
  - Hydrogen from core oxidation
  - Boiling condensation chamber (like a pressure cooker)



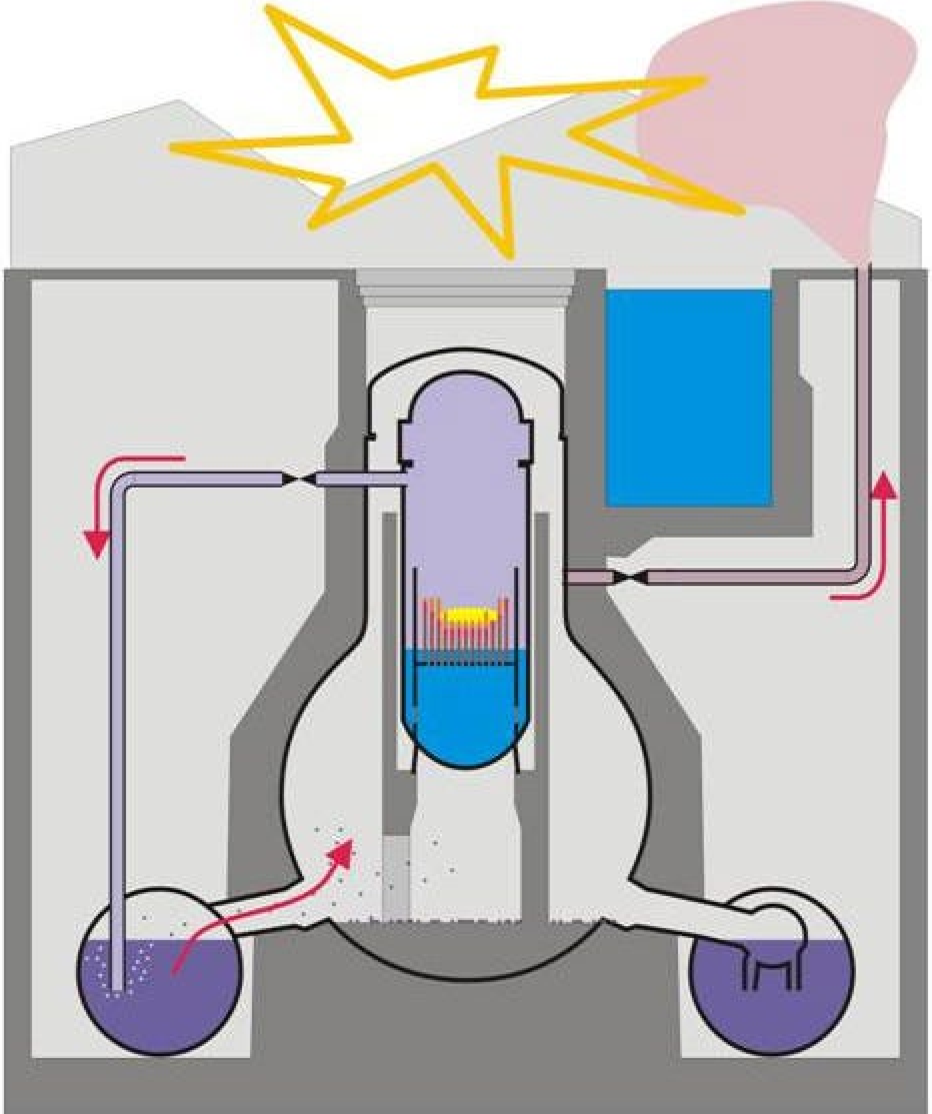
Venting the Containment

- Positive and negative Aspects of depressurizing the containment
  - Removes Energy from the Reactor building (only way left)
  - Reducing the pressure to ~4 bar
  - Release of small amounts of Aerosols (Iodine, Cesium ~0.1%)
  - Release of all noble gases
  - Release of Hydrogen
- Gas is released into the reactor service floor
  - Hydrogen is flammable

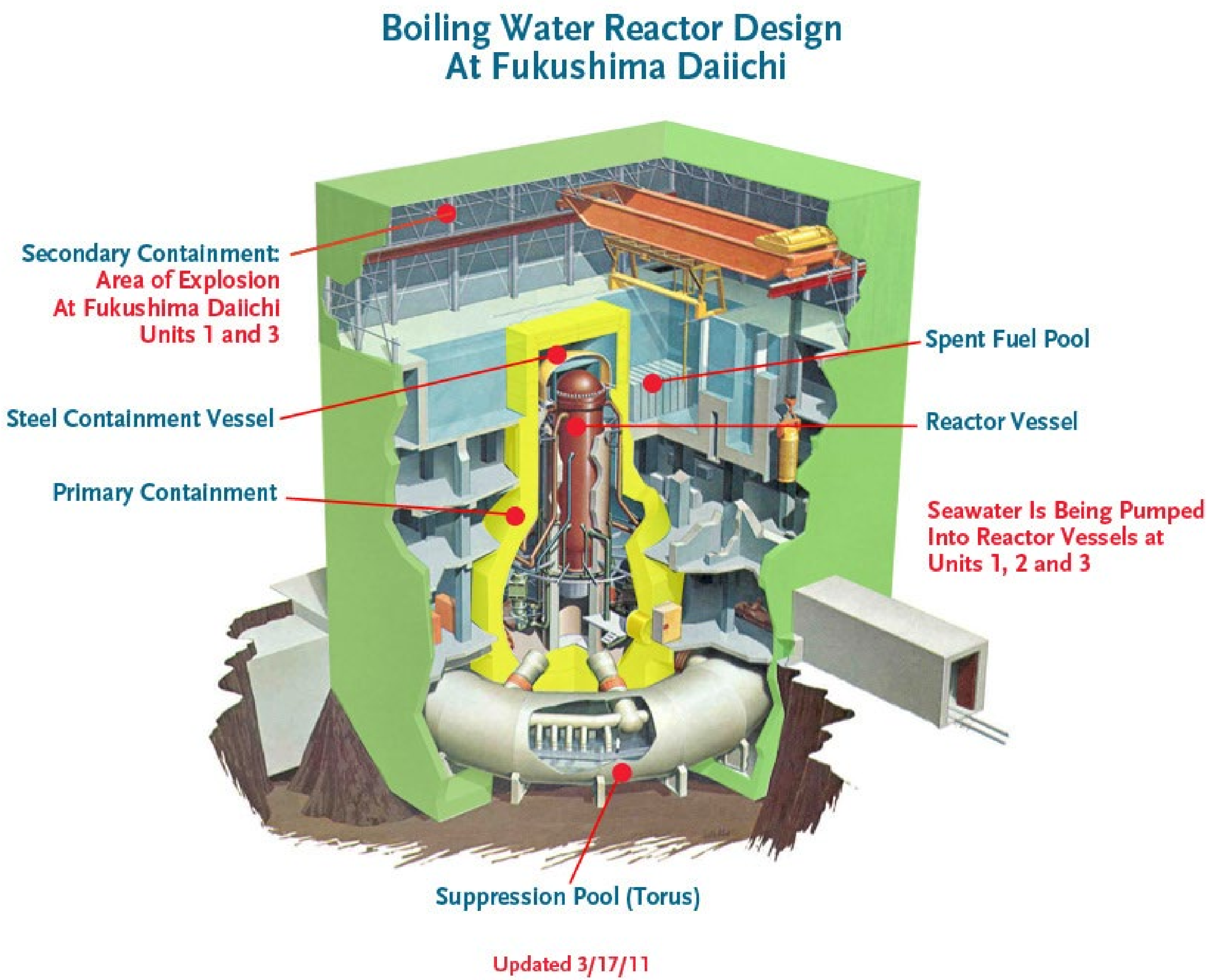


Hydrogen Explosion Units 1 & 3

- Unit 1 und 3
  - Hydrogen burn inside the reactor service floor
  - Destruction of the steel-frame roof
  - Reinforced concrete reactor building seems undamaged
  - Spectacular but minor safety relevant

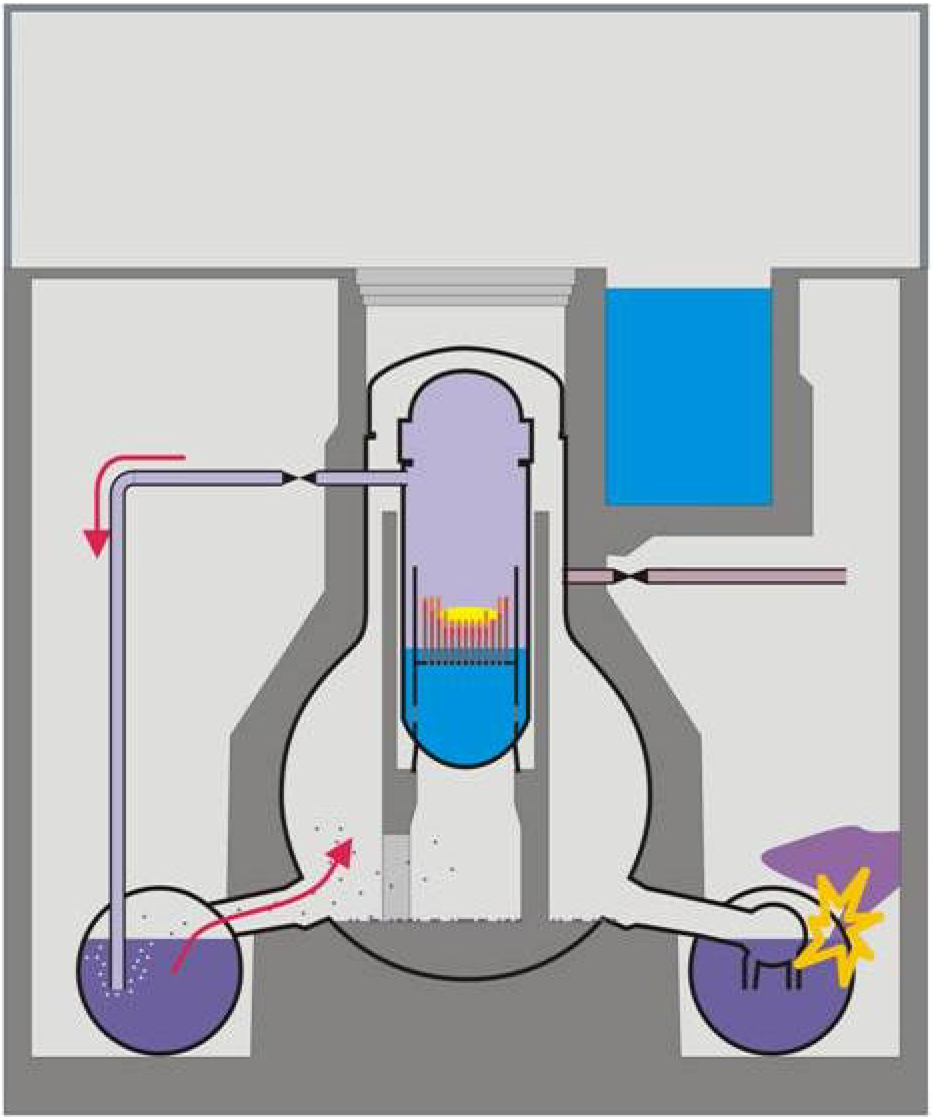


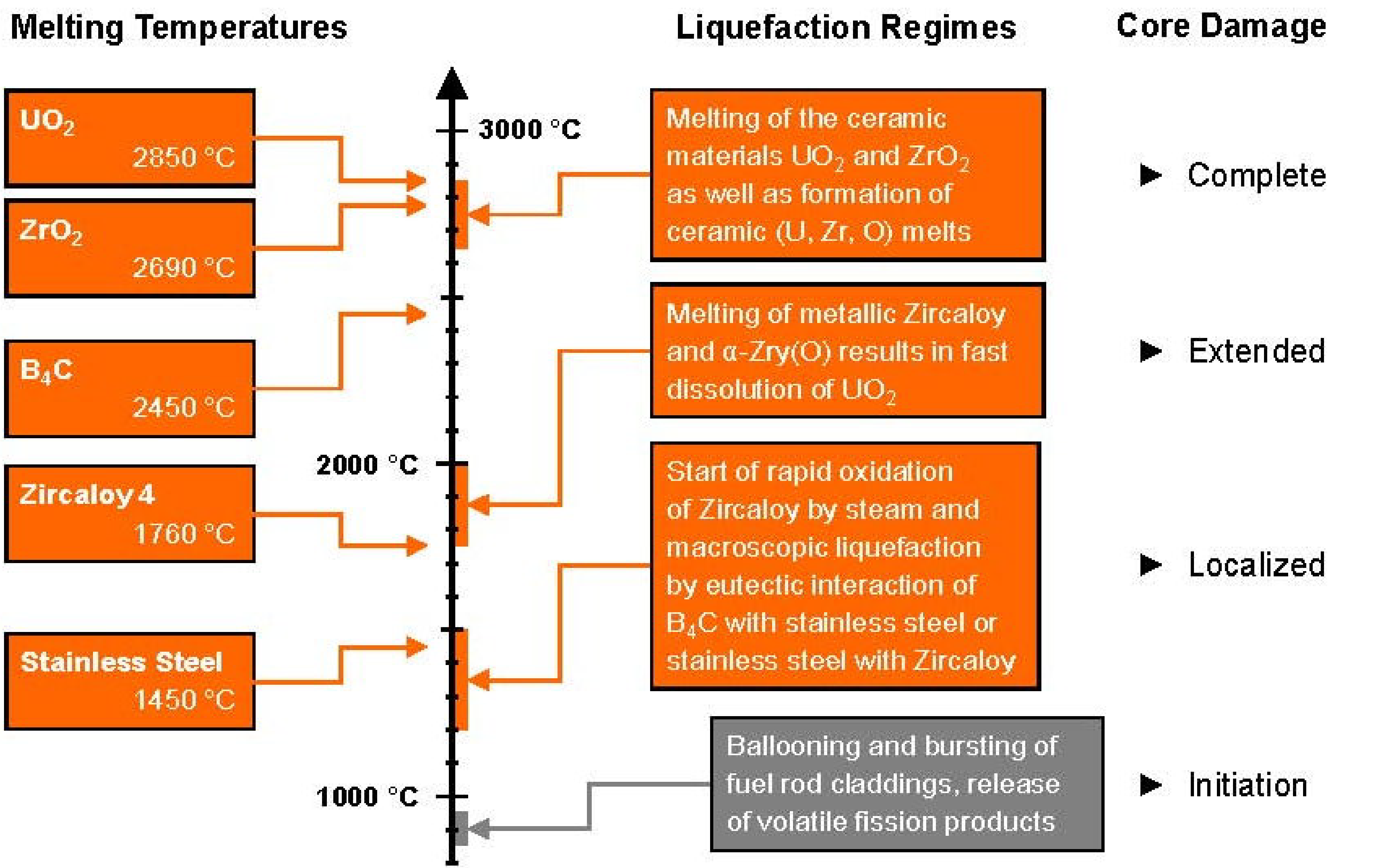

Unit 1 reactor building; top portion damaged from earlier explosion
Unit 3 reactor building; steam is no longer visible venting from the building
Unit 4 reactor building
Unit 2 reactor building; steam can still be seen venting through a hole from removed panel
Image Credit: DigitalGlobe - ISIS
Image Date: March 18, 2011


Boiling Water Reactor Design
At Fukushima Daiichi
Secondary Containment:
Area of Explosion
At Fukushima Daiichi
Units 1 and 3
Steel Containment Vessel
Primary Containment
Spent Fuel Pool
Reactor Vessel
Seawater Is Being Pumped
Into Reactor Vessels at
Units 1, 2 and 3
Suppression Pool (Torus)
Updated 3/17/11

Damage to Torus Unit 2

- Unit 2
  - Hydrogen burn inside the reactor building
  - Probably damage to the condensation chamber (highly contaminated water)
  - Uncontrolled release of gas from the containment
  - **Release of fission products**
  - Temporal evacuation of the plant
  - High local dose rates on the plant site due to wreckage hinder further recovery work
- No clear information on why Unit 2 behaved differently



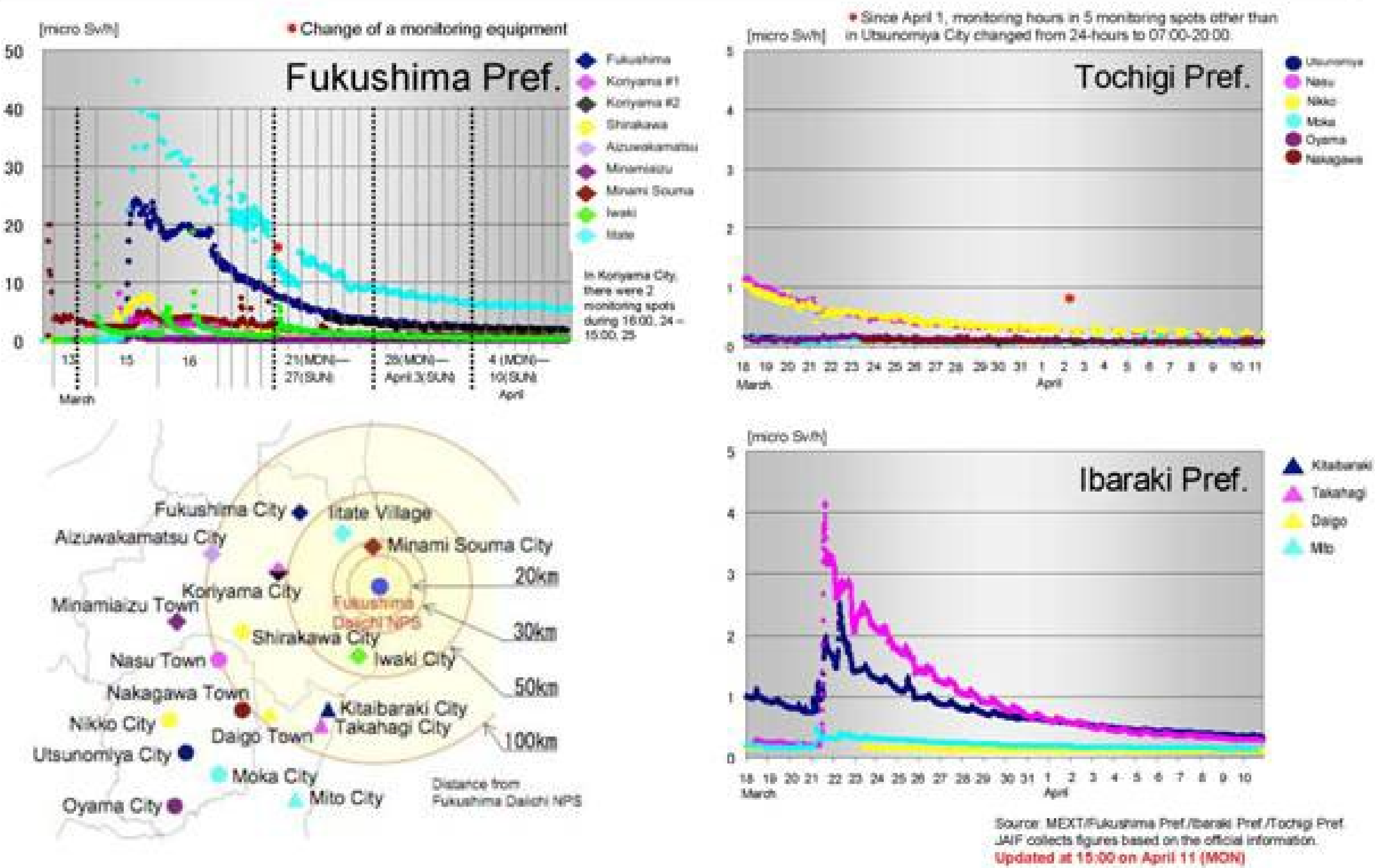


Source: KIT, GRS, 2011

Radiation Levels

- Directly on the plant site
  - Before Explosion in Unit Block 2
    - Below 2mSv / h
    - Mainly due to released radioactive noble gases
    - Measuring posts on west side. Maybe too small values measured due to wind
  - After Explosion in Unit 2 (Damage of the Containment)
    - Temporal peak values 12mSv / h
    - (Origin not entirely clear)
    - Local peak values on site up to 400mSv /h (wreckage / fragments?)
    - Currently stable dose on site at 5mSv /h
    - Inside the buildings a lot more
  - Limiting time of exposure of the workers necessary

Trend of Radiation in the Environment around Fukushima Daiichi NPS

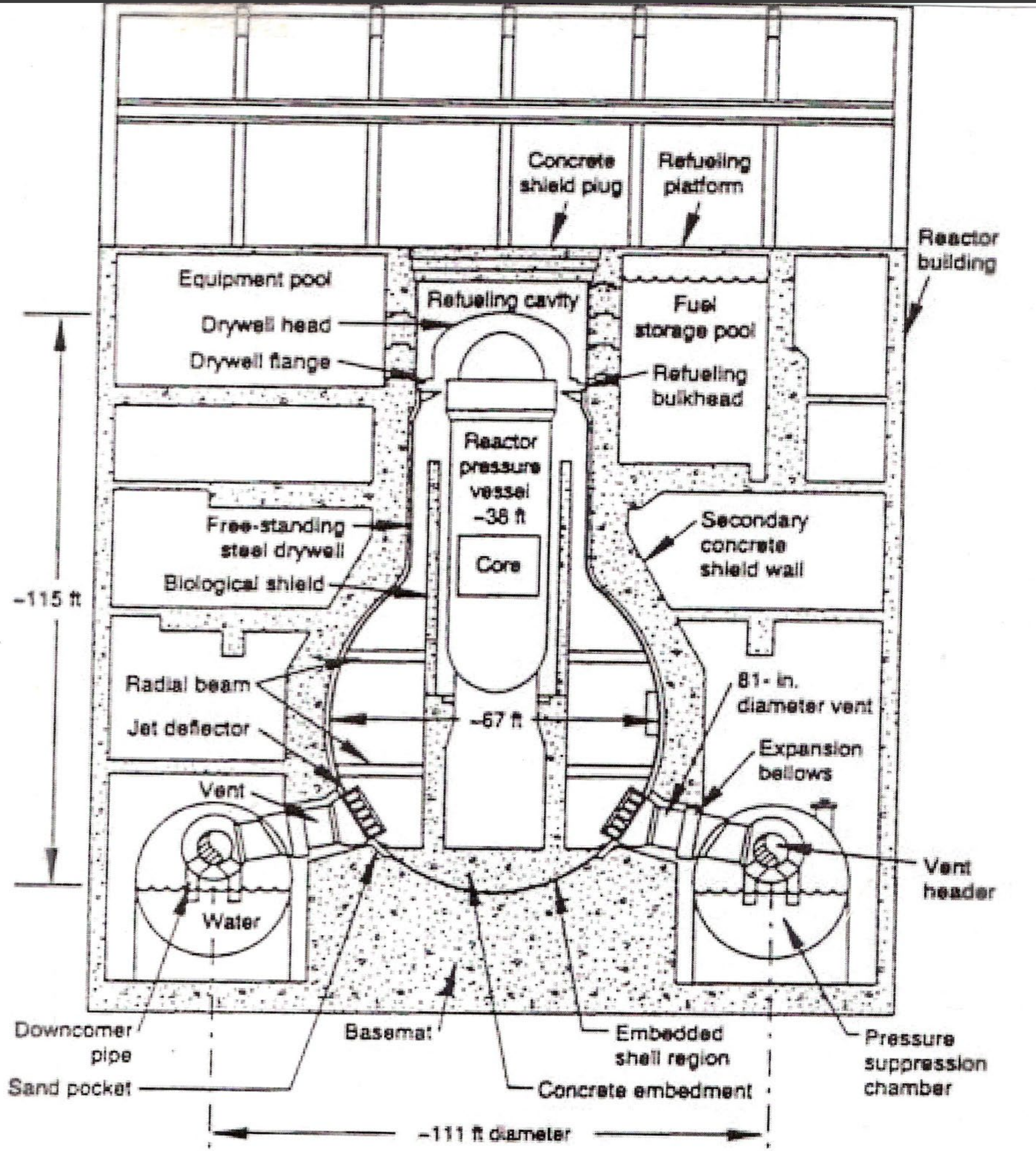


Fukushima Dai-ichi Site Reactor and Fuel Specifications

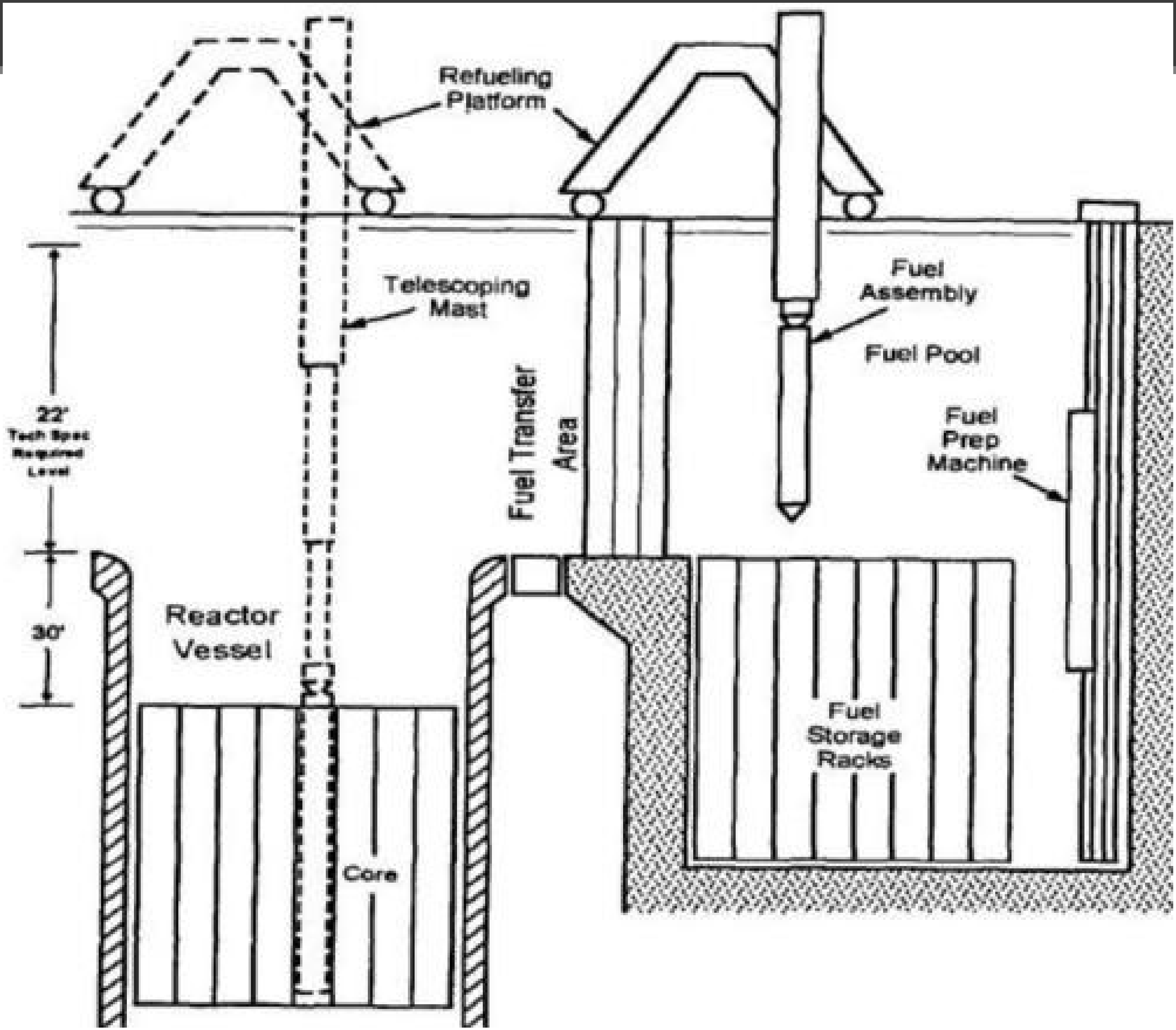
Fukushima Dai-ichi – Tokyo Electric Power Co.				
Reactor No.	Net MWe	Reactor Model	Commercial Start	Reactor Supplier
Unit 1	439	BWR-3	3/71	GE
Unit 2	760	BWR-4	7/74	GE
Unit 3	760	BWR-4	3/76	Toshiba
Unit 4	760	BWR-4	10/78	Hitachi
Unit 5	760	BWR-4	4/78	Toshiba
Unit 6	1067	BWR-5	10/79	GE

Spent Fuel at the Fukushima Dai-Ichi (No.1) Plant

Location	Assemblies in Storage				Heat Generation (1000kcal/h)	Pool Volume (m^3)	Assem-blies in one core	Fuel mass in one core (tons)	Latest inspection
	June 2010	Sept 2010	Dec 2010	March 2011					
Unit 1	292	292	292	292	60	1,020	400	69	3/25/10–10/15/10
Unit 2	471	471	587	587	400	1,425	548	94	9/16/10–12/15/10
Unit 3	366	514	514	514	200	1,425	548	94	6/19/10–10/26/10
Unit 4	783	783	783	1,331	1,600	1,425	548	94	11/30/10–
Unit 5	826	826	826	946	700	1,425	548	94	1/3/11–
Unit 6	692	876	876	876	600	1,497	764	132	8/14/10–
Shared pool	6,375	6,375	6,375						
Dry Cask	408	408	408						
total	10,213	10,545	10,661						



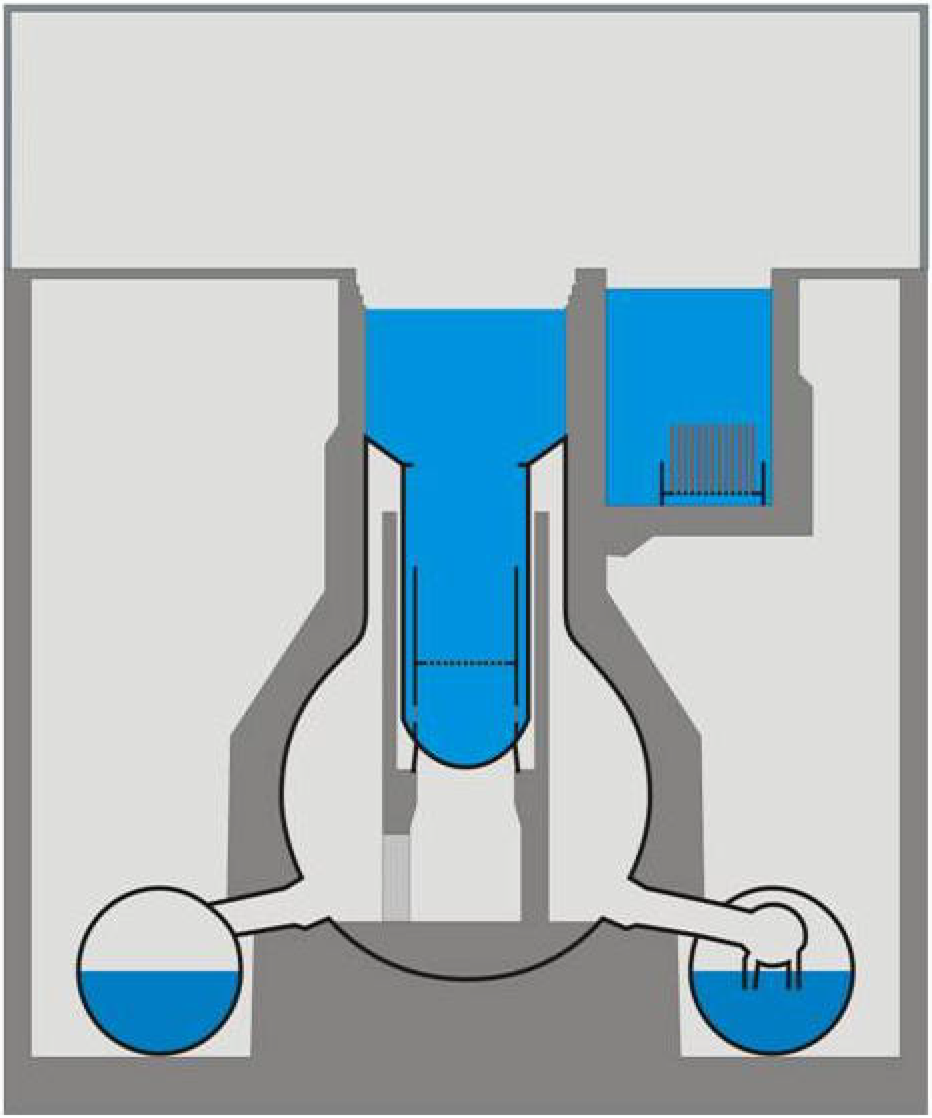
Concrete shield plug
Refueling platform
Reactor building
Equipment pool
Refueling cavity
Fuel storage pool
Drywell head
Drywell flange
Refueling bulkhead
Reactor pressure vessel ~38 ft
Core
Free-standing steel drywell
Biological shield
Secondary concrete shield wall
~115 ft
Radial beam
Jet deflector
~67 ft
81- in. diameter vent
Expansion bellows
Vent
Vent header
Water
Downcomer pipe
Sand pocket
Basemat
Embedded shell region
Concrete embedment
Pressure suppression chamber
~111 ft diameter

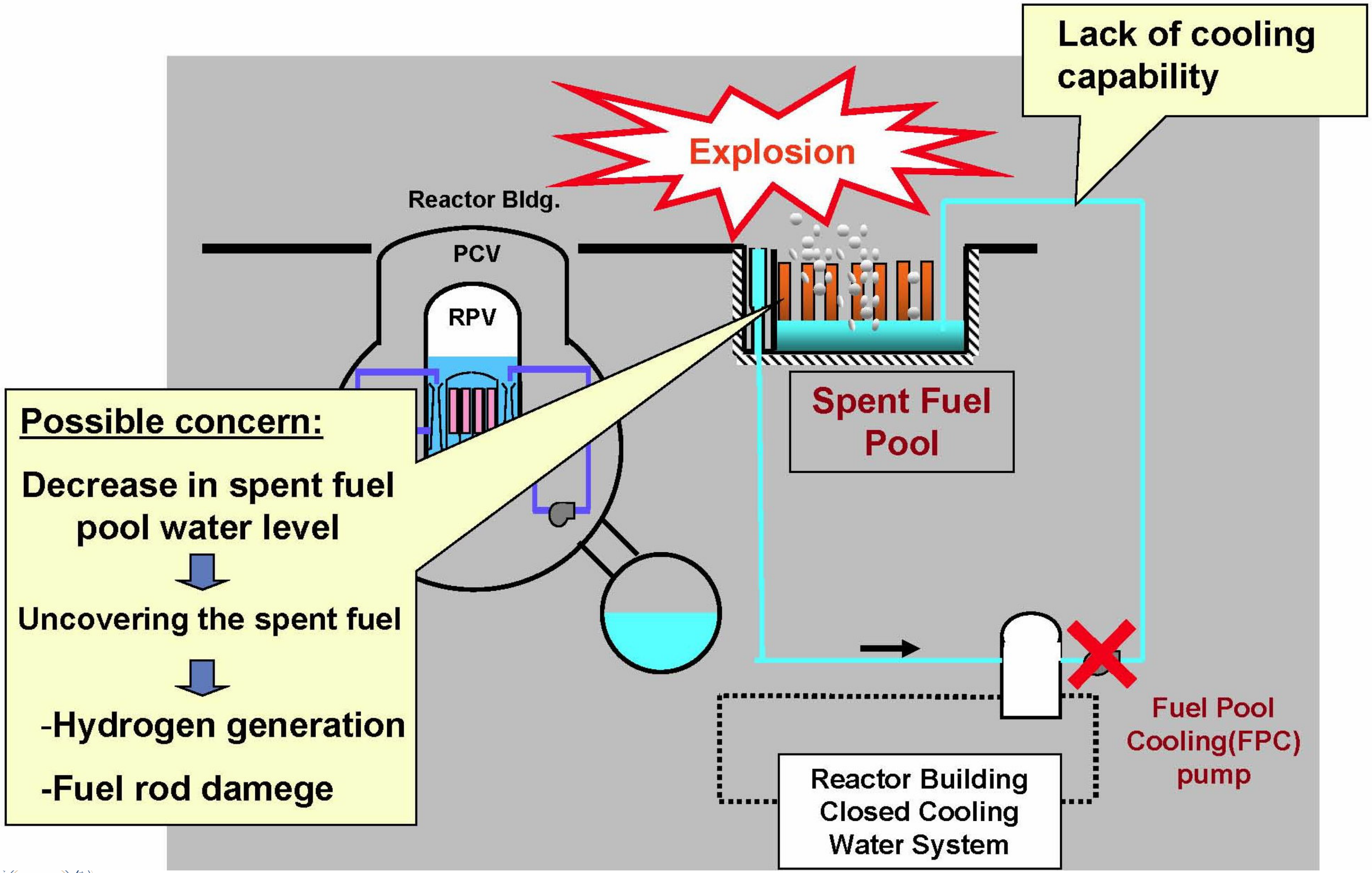


Refueling
Platform
Telescoping
Mast
22'
Tech Spec
Required
Level
30'
Reactor
Vessel
Core
Fuel Transfer
Area
Fuel
Assembly
Fuel Pool
Fuel
Prep
Machine
Fuel
Storage
Racks

- Spent fuel stored in Pool on Reactor service floor
  - Due to maintenance in Unit 4 entire core stored in Fuel pool
  - Dry-out of the pools
    - Unit 4: in 10 days
    - Unit 1-3,5,6 in few weeks
  - **Leakage of the pools due to Earthquake?**

- Consequences
  - Core melt "in fresh air"
  - Nearly no retention of fission products
  - Large release





Lack of cooling capability
Explosion
Reactor Bldg.
PCV
RPV
Spent Fuel Pool
Possible concern:
Decrease in spent fuel pool water level
Uncovering the spent fuel
-Hydrogen generation
-Fuel rod damege
Fuel Pool Cooling(FPC) pump
Reactor Building Closed Cooling Water System

Status of nuclear power plants in Fukushima as of 12:00, May 5th (Estimated by JAIF)

Power Station	Fukushima Dai-ichi Nuclear Power Station			
Unit	1	2	3	4
Electric / Thermal Power output (MW)	460 / 1380	784 / 2381	784 / 2381	784 / 2381
Type of Reactor	BWR-3	BWR-4	BWR-4	BWR-4
Operation Status at the earthquake occurred	In Service -> Shutdown	In Service -> Shutdown	In Service -> Shutdown	Outage
Fuel assemblies loaded in Core	400	548	548	No fuel rods
Core and Fuel Integrity (Loaded fuel assemblies)	Damaged (55%*1)	Damaged (35%*1)	Damaged (30%*1)	No fuel rods
Reactor Pressure Vessel structural integrity	Unknown	Unknown	Unknown	Not Damaged
Containment Vessel structural integrity	Not Damaged (estimation)	Damage and Leakage Suspected	Not damaged (estimation)	Not Damaged
Core cooling requiring AC power 1 (Large volumetric freshwater injection)	Not Functional	Not Functional	Not Functional	Not necessary
Core cooling requiring AC power 2 (Cooling through Heat Exchangers)	Not Functional	Not Functional	Not Functional	Not necessary
Building Integrity	Severely Damaged (Hydrogen Explosion)	Slightly Damaged	Severely Damaged (Hydrogen Explosion)	Severely Damaged (Hydrogen Explosion)
Water Level of the Rector Pressure Vessel	Fuel exposed partially or fully	Fuel exposed partially or fully	Fuel exposed partially or fully	Safe
Pressure / Temperature of the Reactor Pressure Vessel	Gradually increasing / Decreased a little after increasing over 400℃ on Mar. 24th	Unknown / Stable	Unknown	Safe
Containment Vessel Pressure	Decreased a little after increasing up to 0.4Mpa on Mar. 24th	Stable	Stable	Safe
Water injection to core (Accident Management)	Continuing (Switch from seawater to freshwater)	Continuing (Switch from seawater to freshwater)	Continuing (Switch from seawater to freshwater)	Not necessary
Water injection to Containment Vessel (AM)	Feed water to fill up the CV (started 4/27)	Feed water to fill up the CV (planned)	Feed water to fill up the CV (planned)	Not necessary
Containment Venting (AM)	Temporally stopped	Temporally stopped	Temporally stopped	Not necessary
Fuel assemblies stored in Spent Fuel Pool	292	587	514	1331
Fuel Integrity in the spent fuel pool	Unknown	Unknown	Damage Suspected	some of the spent fuel may have been damaged*3
Cooling of the spent fuel pool	Water spray continues (freshwater)	water injection continues (Switch from seawater to freshwater)	Water spray and injection continues (Switch from seawater to freshwater)	Water spray and injection continues (Switch from seawater to freshwater), Hydrogen from the pool exploded (3/15)
Main Control Room Habitability & Operability	Poor due to loss of AC power (Lighting and parmaeter monitoring restored in the control room at Unit 1 and 3 on Mar. 24th, at Unit 2 on Mar. 26th, at Unit 4 on Mar. 29th)			

Environmental effect	●Status in Fukushima Dai-ichi NPS site Radiation level: 417μSv/h at the south side of the office building, 46μSv/h at the Main gate, 18μSv/h at the West gate, as of 09:00, May 5th. Small amounts of Radioactive nuclides(I, Cs, Pu, Am and Cm) has been detected in soil sampled at the Fukushima site.(4/27) Radioactive materials continues to be detected in samples corrected from underground water and sea water at or near the site. Environmental monitoring has been enhanced. Radioactive Iodine and cesium have been detected in the seabed samples taken 15-20 km far from the plant from 15-20m deep. Level of radiation is 100 to 1,000 times above normal. (5/4) ●Influence to the people's life Radioactive material was detected from milk, agricultural products and seafood from Fukushima and neighboring prefectures. The government issued order to limit shipment and intake of some products. Radioactive iodine, exceeding the provisional legal limit for drinking water, was detected from tap water sampled in some prefectures. Radioactive cesium was detected in the sludge from a sewage treatment plant 50 km far from the power station. Small amount of strontium was detected in some samples of soil and plants corrected in the area that is 20-80 km far from the power station.			
Evacuation	<1> Shall be evacuated for within 3km from NPS, Shall stay indoors for within 10km from NPS (issued at 21:23, Mar. 11th) <2> Shall be evacuated for within 10km from NPS (issued at 05:44, Mar. 12th) <3> Shall be evacuated for within 20km from NPS (issued at 18:25, Mar. 12th) <4> Shall stay indoors (issued at 11:00, Mar. 15th), Should consider leaving (issued at 11:30, Mar. 25th) for from 20km to 30km from NPS <5>The 20km evacuation zone around the Fukushima Daiichi NPS is to be expanded so as to include the area, where annual radiation exposure is expected to be above 20mSv. People in the expanded zone are ordered to evacuate within a month or so. People living in the 20 to 30km and other than the expanded evacuation area mentioned above, are asked to get prepared for staying indoors or evacuation in an emergency (announced on Apr. 11th and issued on Apr. 22nd).			
INES (estimated by NISA)	Level 7*2 ※Cumulative amount of radioactivity from Fukushima Diichi NPS has reached the level to be classified as level 7. Total amount of radioactive materials released to the environment in this accident is one tenth as much as one in the Chernobyl accident so far.	Level 3 *2	–	–
Remarks	●Progress of the work to restore cooling function High radiation circumstance hampering the work to restore reactor cooling function at unit-1,2 and 3. Operation to discharge radioactive water in the basement of the buildings and concrete tunnels outside the buildings of all Unit 1, 2, 3, started with unit 2 on April 19 and counties. Emergency power generators were moved to higher ground in order to prevent the reactors' cooling systems from failing in case a major tsunami hits the plant again. External power source becomes more reliable after connecting 3 power lines with each other, which are for Unit 1/2, for Unit 3/ 4 and for Unit 5/6. TEPCO announced its plan to bring the damaged reactors to a stable condition known as a "cold shutdown" in about six to nine months, a situation in which water temperatures inside the reactors have been stably brought below 100 C.(4/17) The damaged containment vessel of unit 2 is need to be repaired before the work to restore reactor cooling function. ●Function of containing radioactive material It is presumed that radioactive material inside the reactor vessel may leaked outside. NISA estimated that the reactor pressure vessel of Unit 2 and 3 may have lost air tightness. Nitrogen gas injection into the Unit 1containment vessel to prevent hydrogen explosion started on April 6th and continues. ●Cooling the spent fuel pool (SFP) Injecting and/or spraying water to the SFP continues for the purpose cooling and make up water evaporated. The walls of the reactor building supporting the pool were severely damaged by an explosion on March 15th at unit-4. Work for structural reinforcement to support the SFP is necessary. ●Prevention of the proliferation of radioactively contaminated substance: TEPCO announced the plans to prevent radioactively contaminated water, dust and soil and radioactive material itself existing on site from spreading on Apr 17. Full operation of spraying synthetic resin to contain contaminated dust started on Apr. 26th and continues.			

[Source]
Government Nuclear Emergency Response Headquarters:
News Release (-5/1 17:00), Press conference
NISA: News Release (-5/3 15:00), Press conference

[Abbreviations]
MEXT: Ministry of Education, Culture, Sports, Science and Technology
INES: International Nuclear Event Scale
NISA: Nuclear and Industrial Safety Agency
TEPCO: Tokyo Electric Power Company, Inc.
NSC: Nuclear Safety Commission of Japan

*1 TEPCO's estimation revised on April 27
*2 Correction: Rating was raised from 5 to 7 for the accident of Unit 1 through 3
*3 It is presumed that some of the spent fuel may have been damaged based on radioactive substance detected from the water sample taken from the pool of Unit 4.

[Significance judged by JAIF]
Low
High
Severe (Need immediate action)

Accidents of Fukushima Daiichi Nuclear Power Stations

as of 12:00, May 5th

1. Latest Major event and response

May 1st
09:00-16:15 Four containers of contaminated debris was remved using remote-controled heavy machines.
10:3014:00 The operation of spraying synthetic resin to prevent contaminated dust and soil from spreading was conducted.
13:35 The operation to block the vertical concrete tunnel outside the Unit 2 T/B started.
14:00-17:00 The operation of transferring water accumulated in the Unit 6 T/B to the makeshift tank was conducted.
May 2nd
09:00-16:00 The operation of spraying synthetic resin to prevent contaminated dust and soil from spreading was conducted.
Work for setting up a local ventilation uniit to improve the work environment in the Unit 1 R/B was started.
.May 3rd
14:00-17:00 The operation of transferring water accumulated in the Unit 6 T/B to the makeshift tank was conducted.

2. Chronology of Nuclear Power Stations

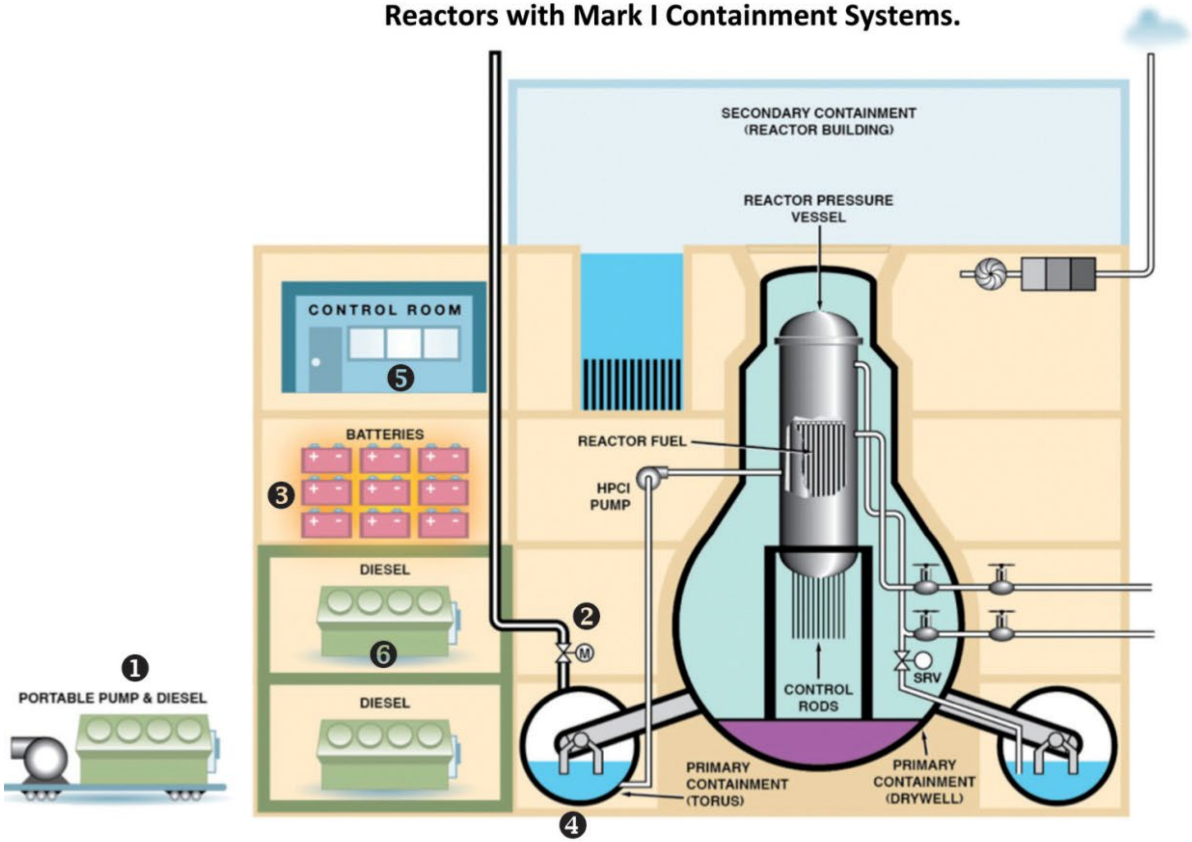
(1) Fukushima Dai-ichi NPS

	Unit 1	Unit 2	Unit 3	Unit 4	Unit-5 and 6
Major Incidents and Actions	11th 15:42 Report IAW Article 10* (Loss of power)	11th 15:42 Report IAW Article 10* (Loss of power)	11th 15:42 Report IAW Article 10* (Loss of power)	14th 04:08 Water temperature in Spent Fuel Storage Pool increased at 84℃	19th 05:00 Cooling SFP with RHR-pump started at Unit 5
*The Act on Special Measures Concerning Nuclear Emergency Preparedness	11th 16:36 Event falling under Article 15* occurred (Incapability of water injection by core cooling function)	11th 16:36 Event falling under Article 15* occurred (Incapability of water injection by core cooling function)	12th 20:41 Start venting	15th 09:38 Fire occurred on 3rd floor (extinguished spontaneously)	19th 22:14 Cooling SFP with RHR-pump started at Unit 6
	12th 00:49 Event falling under Article 15* occurred (Abnormal rise of CV pressure)	13th 11:00 Start venting	13th 05:10 Event falling under Article 15* occurred (Loss of reactor cooling functions)	16th 05:45 Fire occurred (extinguished spontaneously)	20th 14:30 Cold shutdown achieved at Unit 5. 20th 19:27 Cold shutdown achieved at Unit 6.
	12th 14:30 Start venting	14th 13:25 Event falling under Article 15* occurred (Loss of reactor cooling functions)	13th 08:41 Start venting	Since 20th, operation of spraying water to the spent fuel pool continues.	22nd 19:41 All power source was switched to external AC power at Unit 5 and 6.
	12th 15:36 Hydrogen explosion	14th 16:34 Seawater injection to RPV	13th 13:12 Seawater injection to RPV	29th 11:50 lights in the main control room becomes available	
	12th 20:20 Seawater injection to RPV	14th 22:50 Report IAW Article 15* (Abnormal rise of CV pressure)	14th 05:20 Start venting		Apr. 1st 13:40 Start transferring pooled water in the Unit 6 radioactive waste process facility to the Unit 5 condenser.
	22nd 11:20 RPV temperature increased	15th 00:02 Start venting	14th 07:44 Event falling under Article 15* occurred (Abnormal rise of CV pressure)		
	22nd 02:33 Seawater injection through feed water line started in addition to fire extinguish line	15th 06:10 Sound of explosion, Suppression Pool damage suspected	14th 11:01 Hydrogen explosion		
	24th 11:30 lights in the main control room becomes available	15th 08:25 White smoke reeked	15th 10:22 Radiation dose 400mSv/h		
	25th 15:37 Freshwater injection to the reactor started.	20th 15:05 operation of spraying water to the spent fuel pool started.	16th 08:34, 10:00 White smoke reeked		
	27th 08:30 Continuing to transfer the water in the basement of the turbine building	26th 10:10 Freshwater injection to the reactor started.	Since 17th, operation of spraying water to the spent fuel pool continues.		
	31st 09:20-11:25 Work to remove the water in the trench	26th 16:46 lights in the main control room becomes available	21st 15:55 Slightly gray smoke erupted (18:02 settled)		
	31st 12:00 Start to transfer the water in the CST to the surge tank (- 15:27, Apr. 2)	29th 16:45 Start to transfer the water in the CST to the surge tank	22nd 22:46 lights in the main control room becomes available		
	31st 13:03 Start water injection to SFP	Apr. 2nd 16:25 Start injecting concrete to stop water leakage from the pit near the intake	25th 18:02 Freshwater injection to the reactor started.		
	Apr. 7th 01:31 Injection of Nitrogen gas started after opening all valves through the line.	2nd 17:10 Start transferring water in the conden4er to the CST	28th 17:40 Start to transfer the water in the CST to the surge tank		
	Apr. 10th 09:30 Transfer of water from the main condenser to the CST completed.	Apr. 5th 15:07 Regarding leakage from the pit that is closed to discharge outlet of unit-2, hardening agent was injected to hole dug surrounding the pit. (Apr. 6 05:38 It was confirmed that water flow stopped	Apr. 13 13:50 Installation of silt fences in front of the Unit 3 and 4 seawater screen completed		
	Apr 17 16:00 Start investigation of the inside of R/B using a remote-controlled robot.	Apr. 9th 13:10 Transfer of water from the main condenser to the CST completed.	Apr 17 11:30 Start investigation of the inside of R/B using a remote-controlled robot.		
		Apr. 13th 17:04 Transfer of highly radioactively contaminated wafter accumulated in the trench outside the turbine building to the condenser completed			
		Apr. 15th 14:15 Installation of steel plate in front of Unit 2 seawater screen completed			
		Apr 18 13:42 Start investigation of the inside of R/B using a remote-controlled robot.			
		Apr. 19 10:08 Start transferring highly radioactive water accumulated in the turbine building and the concrete tunnel to the waste processing facility			
	Apr. 3rd 12:18 Switch power supply for water injection pumps to the RPV from power supply vehicles to originally equipped power source				
	Apr. 14 12:20 Installation of silt fences in front of the Unit 1and 2 seawater screen and intake completed				
Major Data *1	Reactor Water level (May 4 11:00) (A) -1700mm, (B) -1700mm	Reactor Water level (May 4 11:00) (A) -1500mm, (B) -2100mm	Reactor Water level (May 4 11:00) (A) -1800mm, (B) -2200mm	SFP water temperature measured with a concrete pump vehicle Apr. 12 : about 90℃ 22 before spray: about 91℃ 23 before spray: about 83℃ 23 after spray : about 66℃ 24 before spray: about 86℃ 24 after spray : about 81℃	Water temperature of SFP Unit 5 40.8℃ (May 4 12:00) Unit 6 36.0℃ (May 4 12:00)
	Reactor pressure (May 4 11:00) (A) 0.450MPaG, (B) 1.265MPaG*2	Reactor pressure (May 4 11:00) (A) -0.020MPaG*2, (B) -0.016MPaG*2	Reactor pressure (May 4 11:00) (A) -0.077MPaG*2, (B) -0.091MPaG*2		
	CV pressure (May 4 11:00) 0.135MPaabs	CV pressure (May 4 11:00) 0.065MPaabs	CV pressure (May 4 11:00) 0.1033MPaabs		
	RPV temperature (May 4 11:00) 137.5℃*2 at feed water line nozzle	RPV temperature (May 4 11:00) 117.0℃ at feed water line nozzle Water temperature in SFP (May 4 11:00) 49.0℃	RPV temperature (May 4 11:00) 128.5℃*2 at feed water line nozzle		
	Thermography (Apr. 26 07:30) CV: 25℃, SFP: 23℃	Thermography (Apr. 26 07:30) Top of R/B: 24℃	Thermography (Apr. 26 07:30) CV: 26℃, SFP: 56℃		

Measures drawn from Fukushima Dai-ichi Nuclear Power Accident

Phase	Emergency Safety Measures	Drastic measures
	Short term	Medium-to-Long term
Expected completion	Approx. 1 month (around mid-April)	Decide as per debate at Accident Investigation Commission, etc.
Target (Required standard)	Depending on tsunami, prevent core damage and occurrence of spent-fuel damage even when 1) all alternate-current power sources, 2) seawater cooling function, and 3) spent-fuel pool cooling function are lost.	Prevent occurrence of disasters taking into account “anticipated tsunami height” to be set by referencing tsunami that caused recent disaster.
Examples of specific measures	<u>Securing equipment</u>: ・Deploy power-supply vehicles (to cool reactors and spent-fuel pools). ・Deploy fire engines (to supply coolant water). ・Deploy fire hoses (to secure water-feeding path from fresh-water tank, sea-water pit, etc.). <u>Developing manual</u>: ・Develop implementation procedures for emergency measures utilizing above-mentioned equipment. <u>Training</u>: ・Implementation of training on emergency measures based on implementation procedures manual.	<u>Securing equipment</u> ・Build seawalls. ・Deploy watertight doors. ・Devise other necessary equipment-related measures. *To be followed by implementation of equipment-related improvements as necessary (e.g.: secure spare air-cooled diesel generators, sea water pump motors). <u>Develop manual</u> <u>Conduct training</u>
Confirmation by NISA, etc.	・Approval of amendment of ministerial ordinance to ensure effectiveness of emergency safety measures as well as operational safety program that incorporates those measures. ・Rigorous vetting of implementation status of emergency safety measures by means of inspection, etc.	
Operators’ response	・Efforts under way to procure equipment. (Locations to set them up also being secured). ・Manual compiled anew drawing on recent accident. Training being implemented. ・Strive to improve emergency safety measures continuously, even after their confirmation, to ensure their reliability.	

Major Modifications and Upgrades to U.S. Boiling Water Reactors with Mark I Containment Systems.



1. Added spare diesel generator and portable water pump – 2002
2. Added containment vent – 1992
3. More batteries in event of station blackout – 1988
4. Strengthened torus – 1980
5. Control room reconfiguration – 1980
6. Back-up safety systems separated – 1979